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The Measurement of Plate Vibration and Sound Radiation from a Turbulent Boundary Layer Manipulator

by

M. Phillips and K. Herbert and P. Leehey

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August 20, 1991

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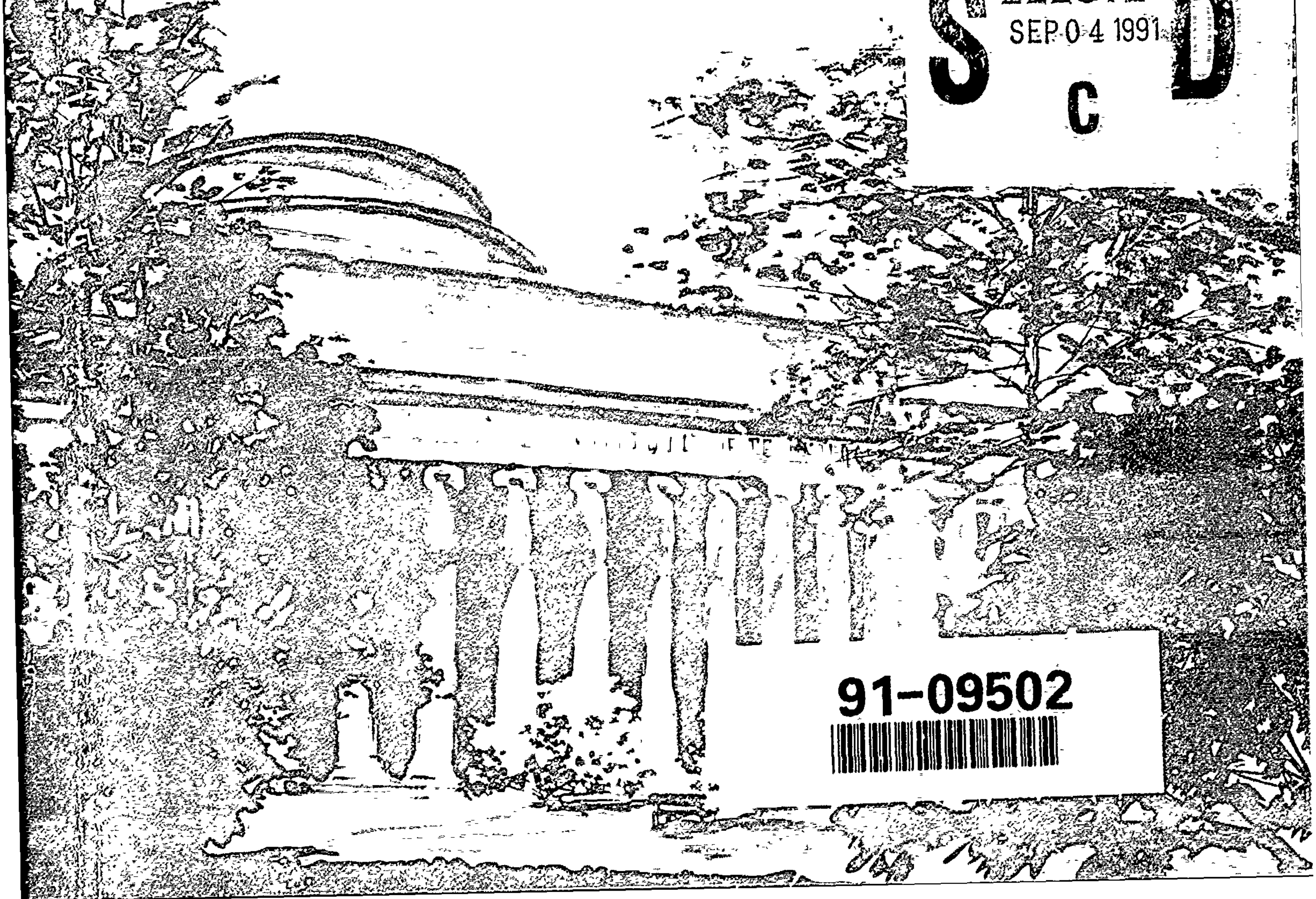
Acoustics and Vibrations Laboratory

Massachusetts Institute of Technology
Cambridge, Massachusetts 02139



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Abstract

Two Boundary Layer Manipulators (BLMs) made of thin honeycombed aluminum were placed in a turbulent boundary layer flow. Sound intensity measurements were taken in order to determine the Mach number dependence of sound radiation. We found that sound intensity levels follow a power law consistent with dipole radiation. We made estimates of intensity levels for the BLMs in water using our measurements in air. Our estimates predict low radiation when mounted on naval vessels. Vibration levels were increased when undamped BLMs were installed in our wind tunnel facility. However, vibration levels were very low, and consequently, sound radiation due to plate vibration was too low to be measured. Damping of the BLMs dramatically reduced vibration levels as well as direct radiation from the BLMs.

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1 Introduction

It has been shown that by placing several Boundary Layer Manipulators (BLMs) in a turbulent boundary flow, the fluctuating wall pressures caused by turbulent eddies in this flow can be greatly reduced. It has been suggested that such devices be used in order to reduce the boundary layer self-noise and vibration of a vehicle traveling in water. In order for such a device to be practical, it must reduce the self-noise level while not radiating so much additional noise as to offset this reduction. For this reason we would like to know the level of radiated noise generated by the addition of these BLMs. By measuring the sound intensity generated by the BLMs at a number of air speeds, we would like to determine a power law relationship between this intensity and the Mach number of the air flow.

2 Experimental Apparatus

2.1 BLM Test Setup

Two aluminum honeycomb BLMs, see Figure (1) were attached to a plexiglass sheet with a silicon sealant. The BLMs were spaced approximately 2.5 inches apart. The dimensions of the test apparatus are shown in Figure (2).

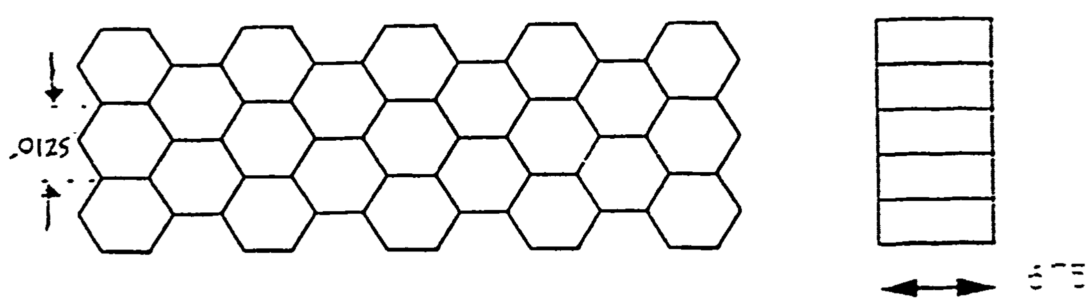


Figure 1: Boundary Layer Manipulator Dimensions

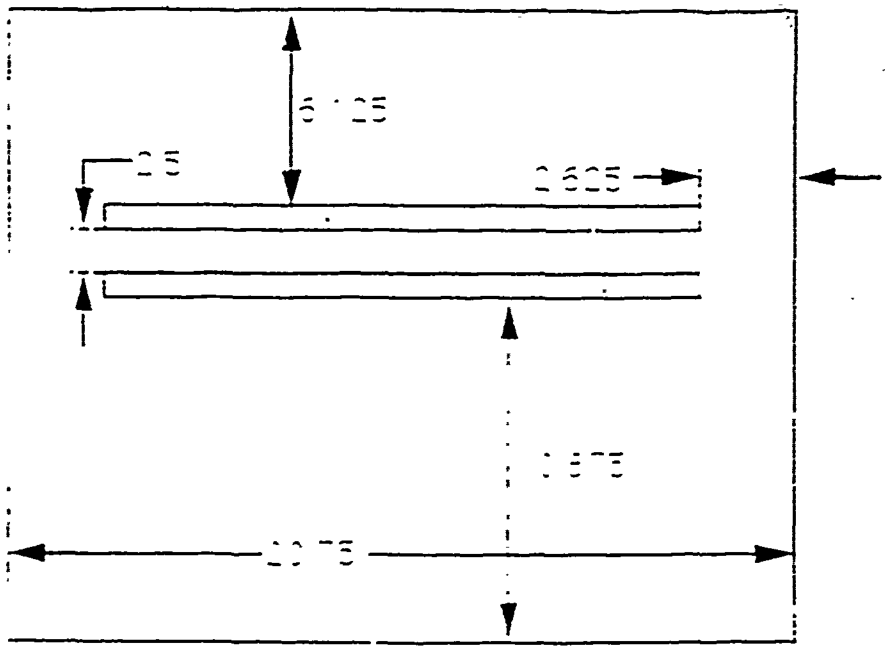


Figure 2: Dimensions of Wind Tunnel Setup

2.2 Intensity Probe and Analyzer Configuration

A Bruel & Kjaer 3519 intensity probe was configured with two .25 inch microphones separated by a 6 mm spacer. This combination is capable of providing valid intensity readings for all frequencies from 400 Hz to 10 kHz. A B&K 2032 analyzer was configured to record sound intensities over a frequency range of 768 Hz to 13.34 kHz, and a Hanning weighting window with maximum sample overlap was used. The analyzer was set to record 1000 linearly averaged samples, as this sample length showed repeatability within .3 dB for several measurements at the same tunnel speed.

The microphones were calibrated using a B&K type 2200 pistonphone. The analyzer was configured to display the averaged pressure spectrum for channel A, and the microphone sensitivity was adjusted until the reported total pressure level matched the 123.9 dB pressure level produced by the pistonphone. This was then repeated for the other microphone.

2.3 Wind Tunnel Setup

The tests were performed in the M.I.T. Acoustics and Vibration Laboratory wind tunnel. The test section was modified slightly in order to make it possible to take readings from above the test apparatus as well as from the side. The top panel covering the flow stream over the test apparatus was removed, leaving the flow open on three sides, with the test setup forming a continuation of the lower tunnel wall. In addition, the collector was modified

slightly in order to reduce noise caused by air reflecting off of the collector panels, see Figure (3). The foam padding was replaced with a thinner rubber-

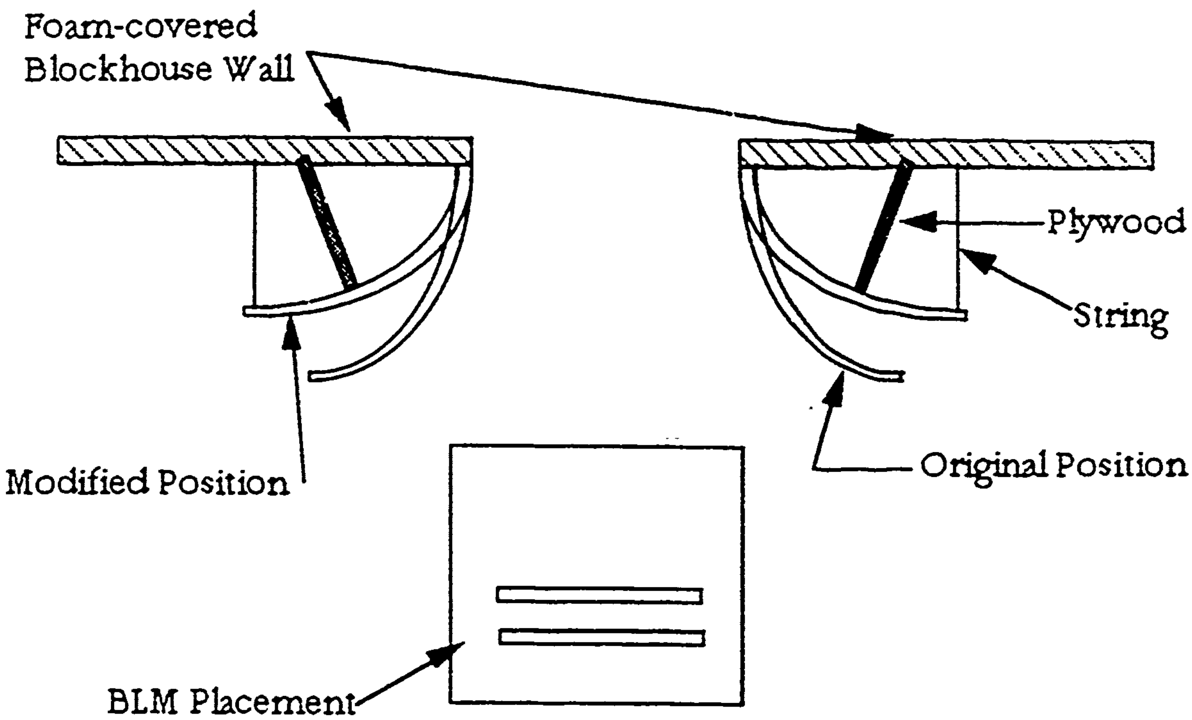


Figure 3: Wind Tunnel Test Section Modification

backed foam padding which was glued to the collector panels so that it would not come loose with the flow at relatively high speeds. Also, the collector panels were attached to the blockhouse wall at a much shallower angle than before, and then propped forward with a plywood spacer in order to support the panel and minimize vibrations. Although the shallower angle of the collector panels may have caused more air to be deflected back against the tunnel flow, the air was deflected behind the measurement control areas, not through them as had been the case with the previous configuration.

2.4 Control Area Specification

Two control areas were defined, one above the BLMs and one to the side of the BLMs. These surfaces were defined by a horizontal scale attached to the edge of the plexiglass plate and a vertical scale attached to the intensity probe handle, in order to eliminate the possibility of sound reflecting off a solid boundary. The surfaces were located at distances of 5 inches from the side of the BLMs and 20 inches above the BLMs, the closest distances at which none of the surface intersected the air flow, in order to reduce interference caused directly by the air flow. All control surfaces had an area at 260 square inches.

2.5 Experimental Procedure

The intensity probe, positioned with the microphone axis perpendicular to the control surface being measured, was swept over each surface several times while the analyzer averaged the readings. For the time required to take the necessary number of averages, the entire surface could be covered several times. In order to ensure that some parts of the control area were not accidentally weighted more heavily than other areas due to more thorough coverage with the intensity probe, it was necessary to do two things. First, for each sweep of the entire control area, the speed at which the probe was swept was kept constant. Second, the entire surface had to be covered a whole number of times. This meant that the speed of the probe had to be adjusted slightly between full surface sweeps in order to ensure that the averaging would not be completed after the probe had only swept half of the control area on a particular sweep. For the higher tunnel speeds, it was common for the intensity probe's microphones to become overloaded due to the increased sound intensity generated by the test apparatus. In order to avoid this problem, the input sensitivity of the analyzer was adjusted to a level at which the equipment did not overload. For the higher tunnel speeds, the gain was set at 150 mV per channel, however in order to retain good resolution the level was dropped in steps down to 40 mV as the tunnel speed was decreased.

The sound intensity was measured at five air speeds, ranging from 36.4 m/s to 15 m/s. Intensity measurements were made with the BLM appa-

ratus in the air flow, and background measurements were made with a flat plexiglass sheet replacing the BLM setup. For all measurements, both the intensity and pressure spectrums were plotted.

3 Theoretical Limits to Intensity Probe Range

3.1 Intensity and Pressure Levels

Sound intensity and pressure levels L_I and L_P are measured in dB, with

$$L_I = 10 \log_{10} \frac{L}{L_0}$$

and

$$L_P = 10 \log_{10} \frac{P^2}{P_0^2}$$

The reference level I_0 for intensity is $1x10^{-12} W/m^2$, whereas the reference level for pressure P_0 is $2x10^{-5} N/m^2$.

3.2 High Frequency Limit

There are several probe characteristics which limit the frequency range over which measurements can be made. The first of these is the microphone spacer length, which determines the high frequency limit for sound intensity measurements. In order for the intensity measurements to be accurate to within 1 dB, the wavelength measured must be at least 6 times the spacer distance. For a microphone separation of 6 mm, the highest wavelength which can be accurately measured is approximately 10 kHz.

3.3 Low Frequency Limit and the Reactivity Index

In order to calculate the intensity level, it is necessary to determine the phase shift of the sound wave across the microphone spacer. However, the measurable phase shift contains not only the actual phase shift but also an added component due to a phase mismatch caused by the instrumentation. In order for the intensity measurements to be accurate to within 1 dB, the

actual phase change of the wave across the spacer must be at least 5 times the phase mismatch of the analyzer.

The actual phase change across the spacer distance is affected by the angle of incidence of the wave to the intensity probe. Since the effective spacer distance is shortened as the angle of incidence increases, the detectable phase change across this distance decreases as well.

The phase change across the spacer can be determined from the difference in sound pressure and intensity levels, $L_P - L_I$, called the *reactivity index*, using the relationship

$$L_I - L_P = 10\log_{10}\left(\frac{\lambda}{\nabla r}\frac{\phi}{360}\right)$$

where ∇r is the microphone spacer distance, λ is the wavelength, and ϕ is the phase change across the spacer.

The phase mismatch of the analyzer is caused by the fact that there is an inherent time delay from one channel of the analyzer to the other, since the measurements from each channel cannot be made simultaneously and instead must be made consecutively. This phase mismatch can be quantified as the *residual intensity index* using the same formula, with the phase mismatch of the analyzer substituted in place of the phase change of the wave.

By comparing the reactivity index and the residual intensity index, the validity of the measurements can be checked. A phase change across the microphone spacer which is 5 times the analyzer's phase mismatch corresponds to a reactivity index which is 7 dB higher than the residual intensity index for a given analyzer mismatch.

In these experiments, the lowest frequency measured was 768 Hz. Using the given analyzer phase mismatch of .30, the formula gives a residual intensity index of −12 dB. This means that the reactivity index of the measurements must be greater than −5 dB in order for the measurements to be accurate to within 1 dB.

4 Analyzer Zoom and Delta Features

Two features of the analyzer were utilized in order to obtain accurate values for the total intensity levels generated by the BLMs. The zoom feature was

used in order to ignore all of the data below 768 Hz as the measurements were taken, and then a delta window was used on the spectrum in order to give a total for the frequency range over which the intensity measurements were valid.

Because of the weighting functions used in the analyzer, the intensity level for a given frequency band is affected by the intensity levels for the bands surrounding it. There was a large low frequency spike in the intensity spectrum below 500 Hz, and this caused an overestimation of the reported intensity totals across a large portion of the spectrum (Figures (4) and (5)).

In order to remove the influence of these low frequency intensities, the zoom feature of the analyzer was used to cut off the measurements in the low frequency range. Intensity measurements were taken with both Hanning and rectangular weightings, and the lower frequency measurement limit was increased until the two weighting methods gave reasonably close results, within 1 dB (Figures (6) and (7)).

Since the Hanning window decays much more rapidly than the rectangular window, the influence of the low frequency spike on higher frequency intensity readings was lower in the Hanning case.

Since the zoom feature only allows frequency band increments of 256 Hz, the low frequency measurement limit had to be set at 768 Hz, as this was the lowest limit which eliminated the effects of the low frequency spike on the higher frequency intensity measurements.

The delta window was used so that the total intensity could be read directly from the analyzer. The low frequency limit was set at 768 Hz, the limit imposed by the zoom feature, and the upper limit was set at 10 kHz, the limit due to the microphone spacer distance. The analyzer was set to report the total intensity contained within this band .

5 Background Intensity Level Measurements

One of the main benefits of measuring sound intensity rather than sound pressure relates to the fact that intensity is a vector quantity whereas pressure is a scalar quantity. This means that background noise sources can be easily eliminated from the total intensity by using a control volume surrounding

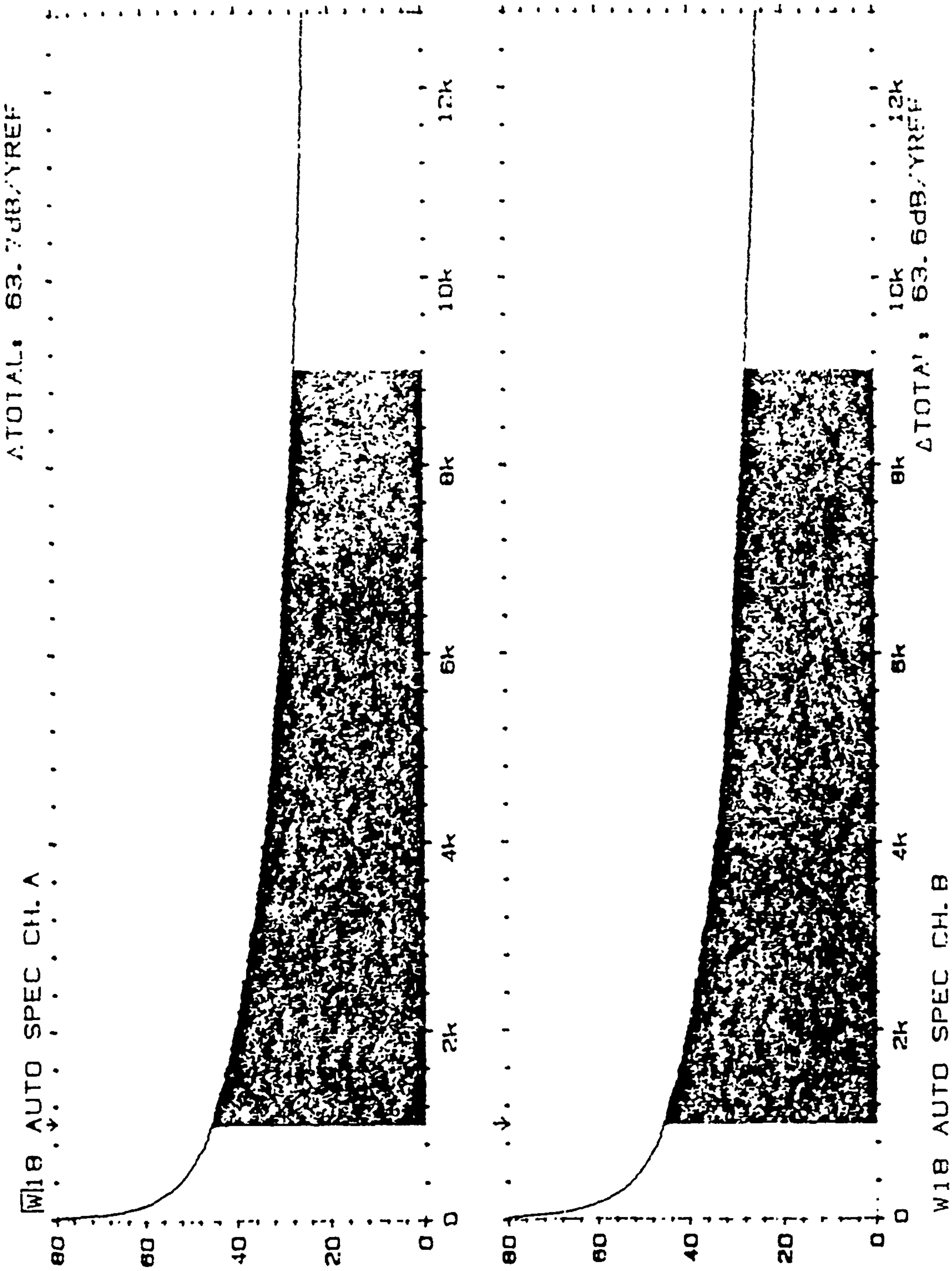


Figure 4: Spectrum Showing Pressure Level Total With Rectangular Weighting

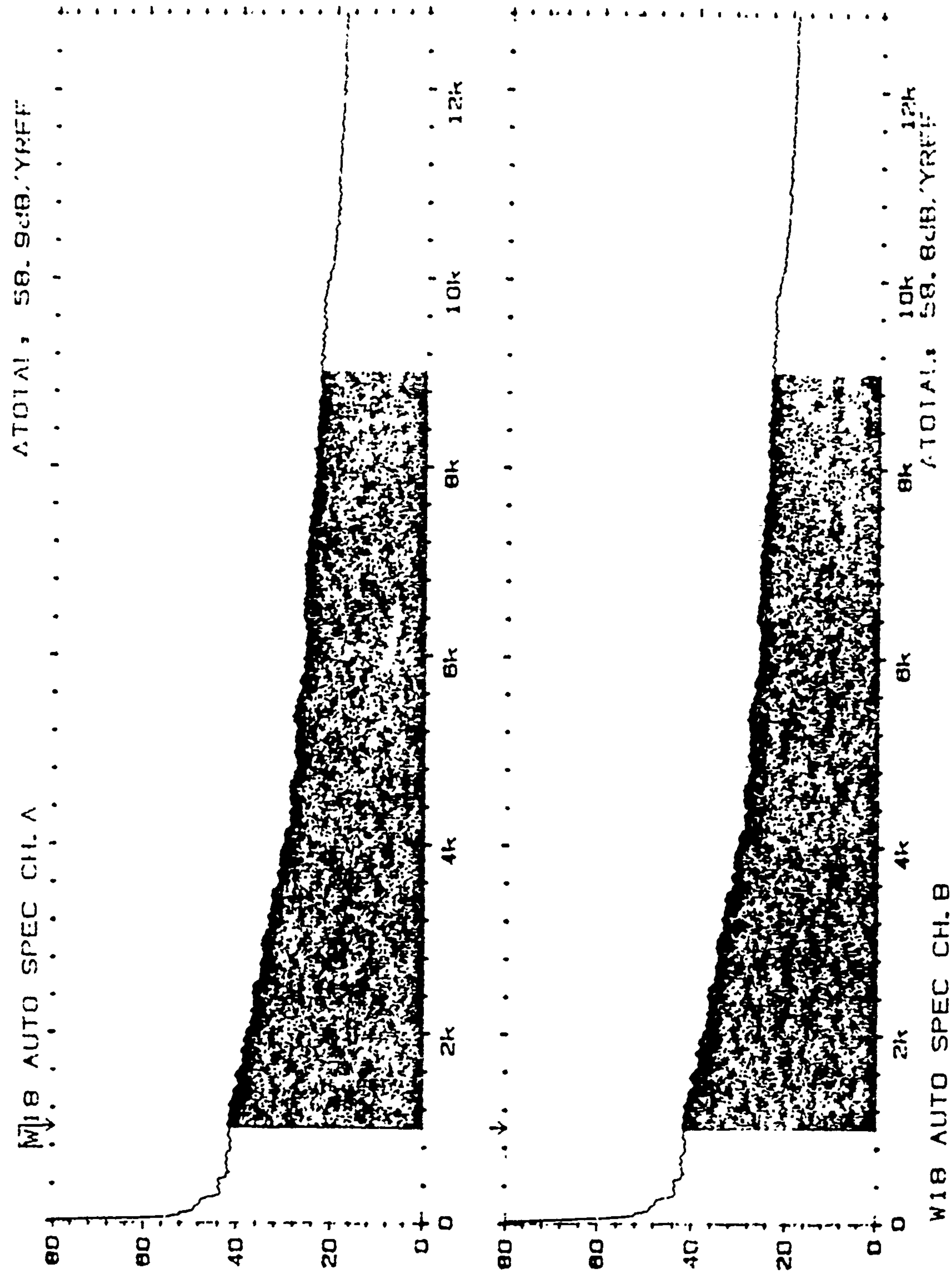


Figure 5: Corresponding Spectrum Showing Pressure Level Total With Hanning Weighting

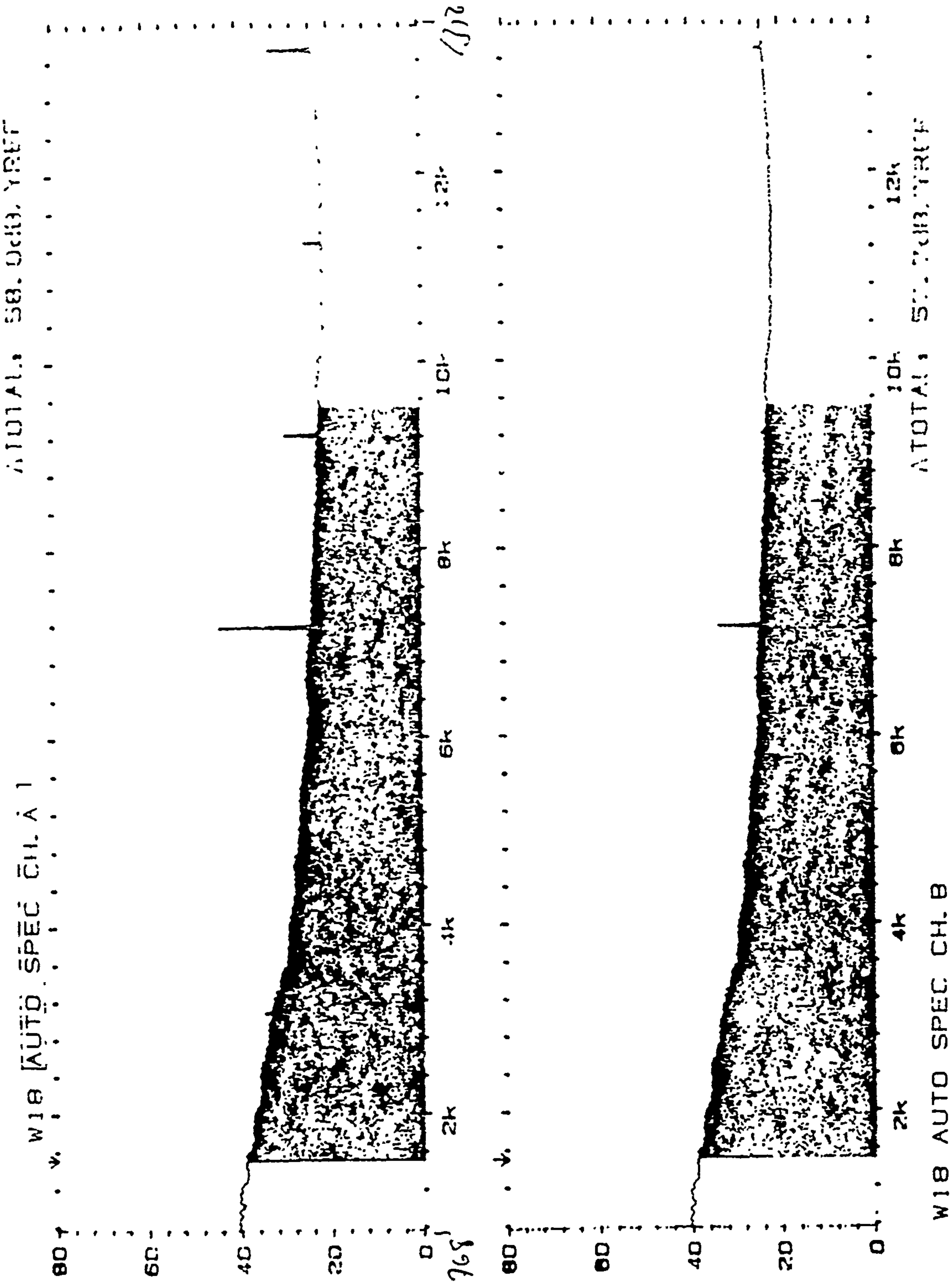


Figure 6: Zoomed Spectrum Showing Pressure Level Total With Rectangular Weighting

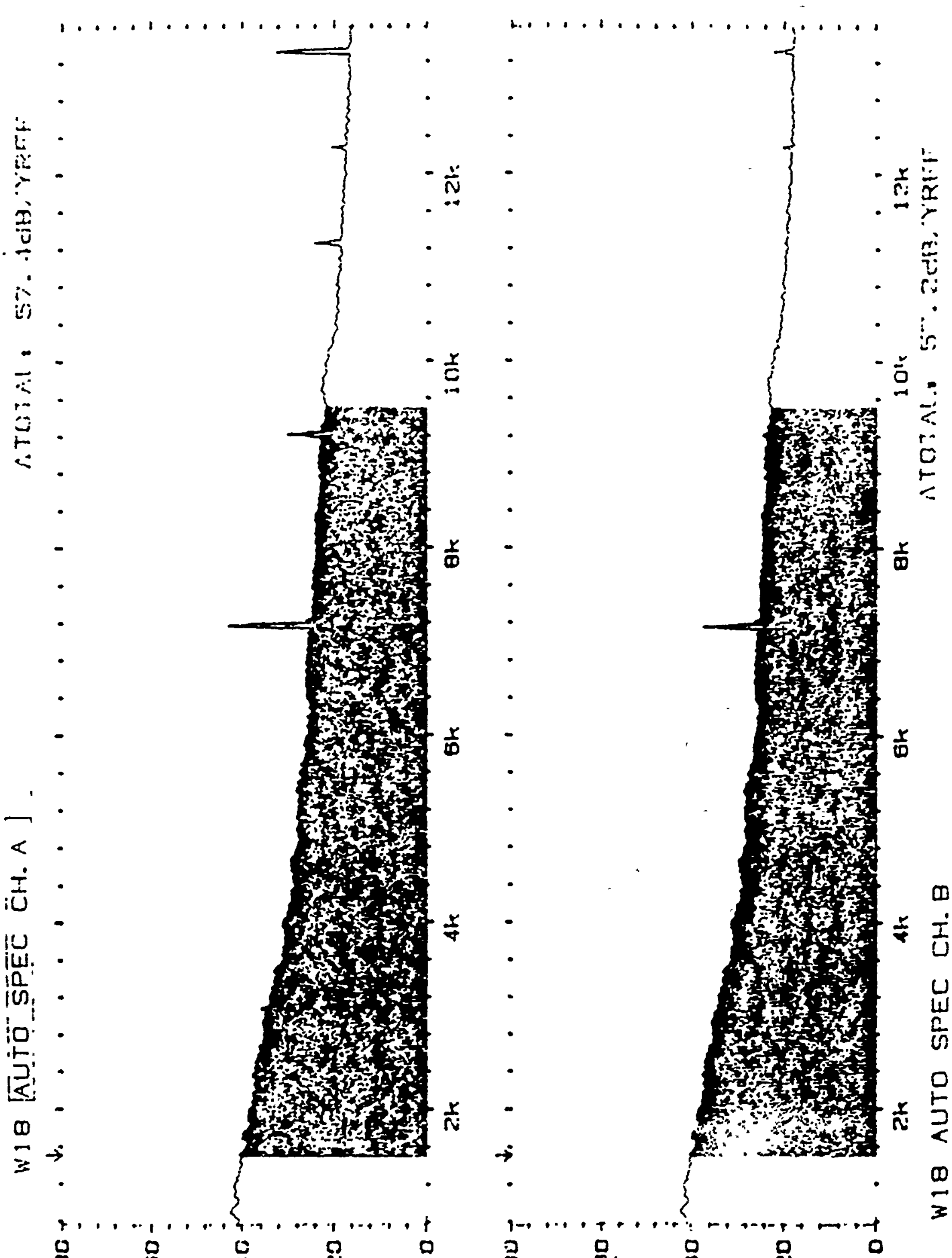


Figure 7: Corresponding Zoomed Spectrum Showing Pressure Level Total With Hanning Weighting

the source of interest. The background sources will radiate sound intensity which enters the control surface on one side an[illegible] on an opposite side with negative intensity, and when the intensi[illegible] [illegible]aled over the control surface the background intensity will cance[illegible]

However, in a wind tunnel this procedure [illegible] applicable. Because of the air flow, the sound intensity over the two fa[illegible]es of the control volume which cut across the flow can not be measured T[illegible] means that background sources, such as the blower, motor, and collector [illegible] not be separated from the actual intensity generated by our test appara[illegible]

To compensate for this, separate background measurements were made in order to determine the sound intensity in the tunnel without the test apparatus in place. These measurements were made using the same control surfaces defined for the measurements with the BLMs in place and the same probe orientations.

6 Experimental Results

Sample intensity and pressure spectra are shown in Figures (8) through (10).

Overall, the background intensity level measurements were much lower than the intensity measurements with the BLMs in place, averaging more than 10 dB lower (Table (1)). Because of this the background noise levels were ignored, as their contributions to the overall intensity level were negligible.

In order to find a power law relationship $I + M^n$ for the sound intensity I and the Mach number of the air flow M, $\log I$ vs. $\log M$ was plotted, and a line with slope n was fitted to the points. These graphs are shown as Figures (11) and (12). The values of n are approximately 6.6 for the intensities radiated above the BLMs as well as to the side of the BLMs.

The total sound intensity level given by the analyzer was used to determine the sound power radiated from the BLMs. The sound intensity was assumed to be radiated from the opposite ends of the BLMs symmetrically. The total sound power vs. Mach number is shown in Figure (13).

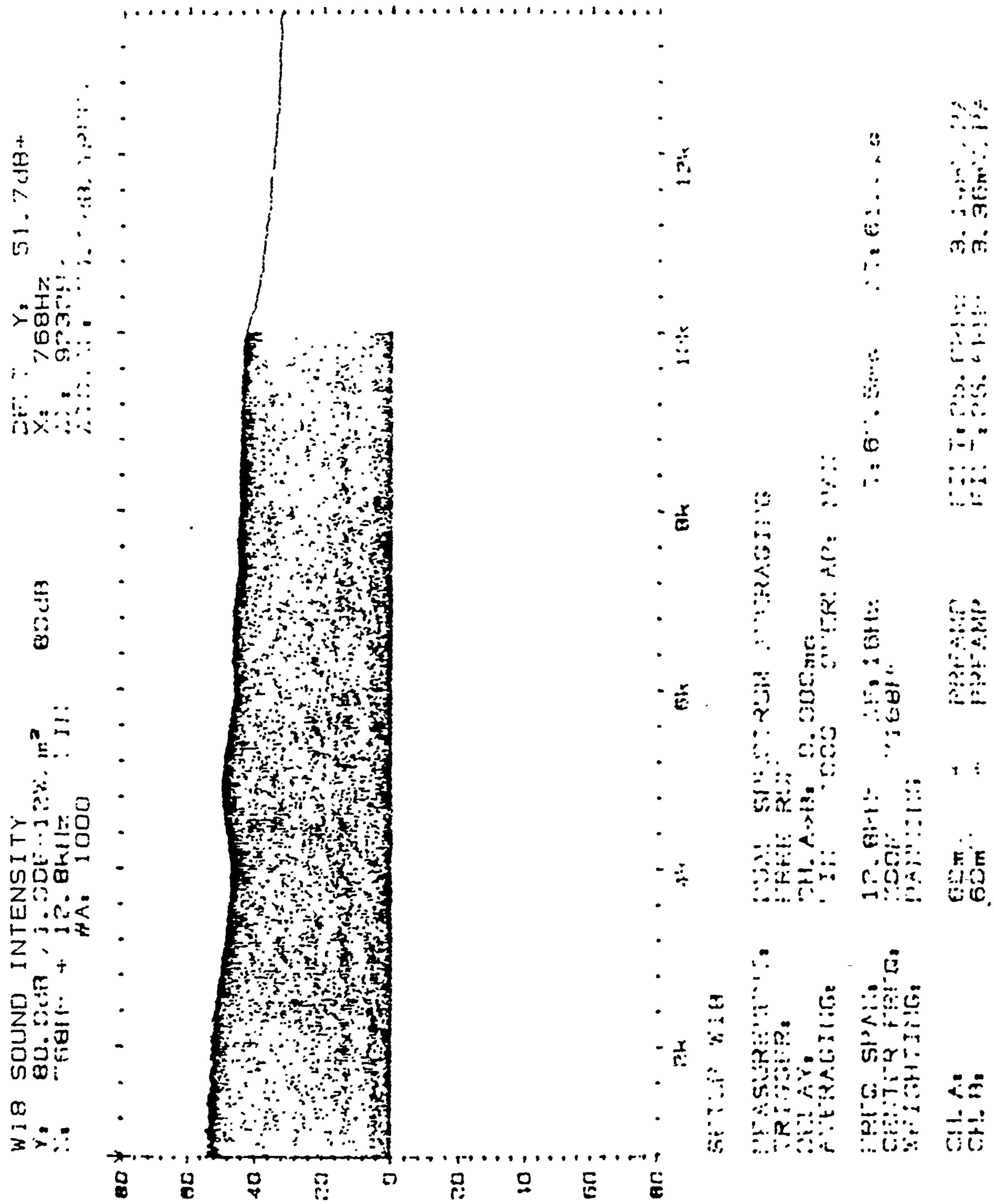


Figure 8: Sample Intensity Spectrum

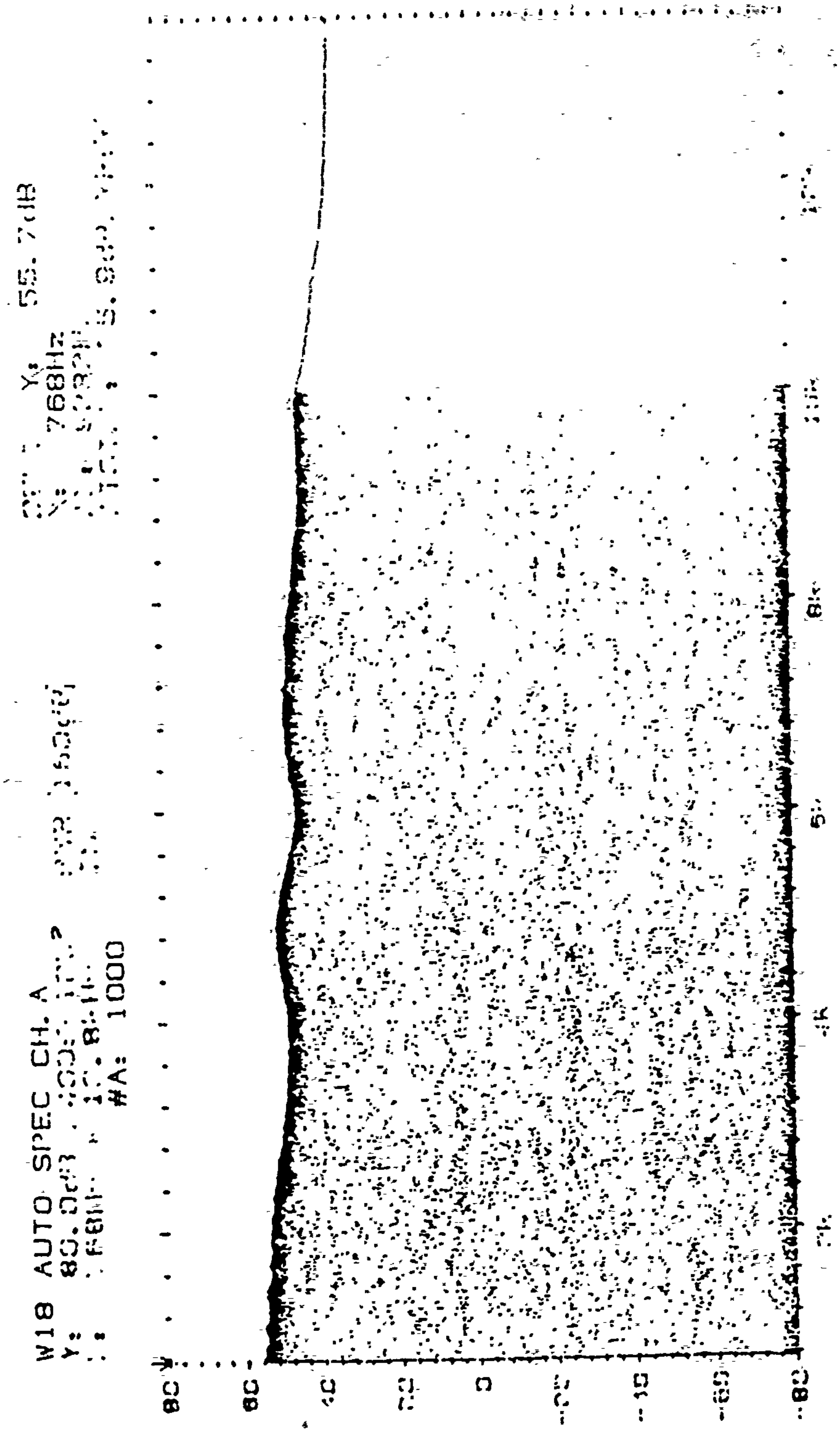


Figure 9: Sample Pressure Level Spectrum, Channel A.

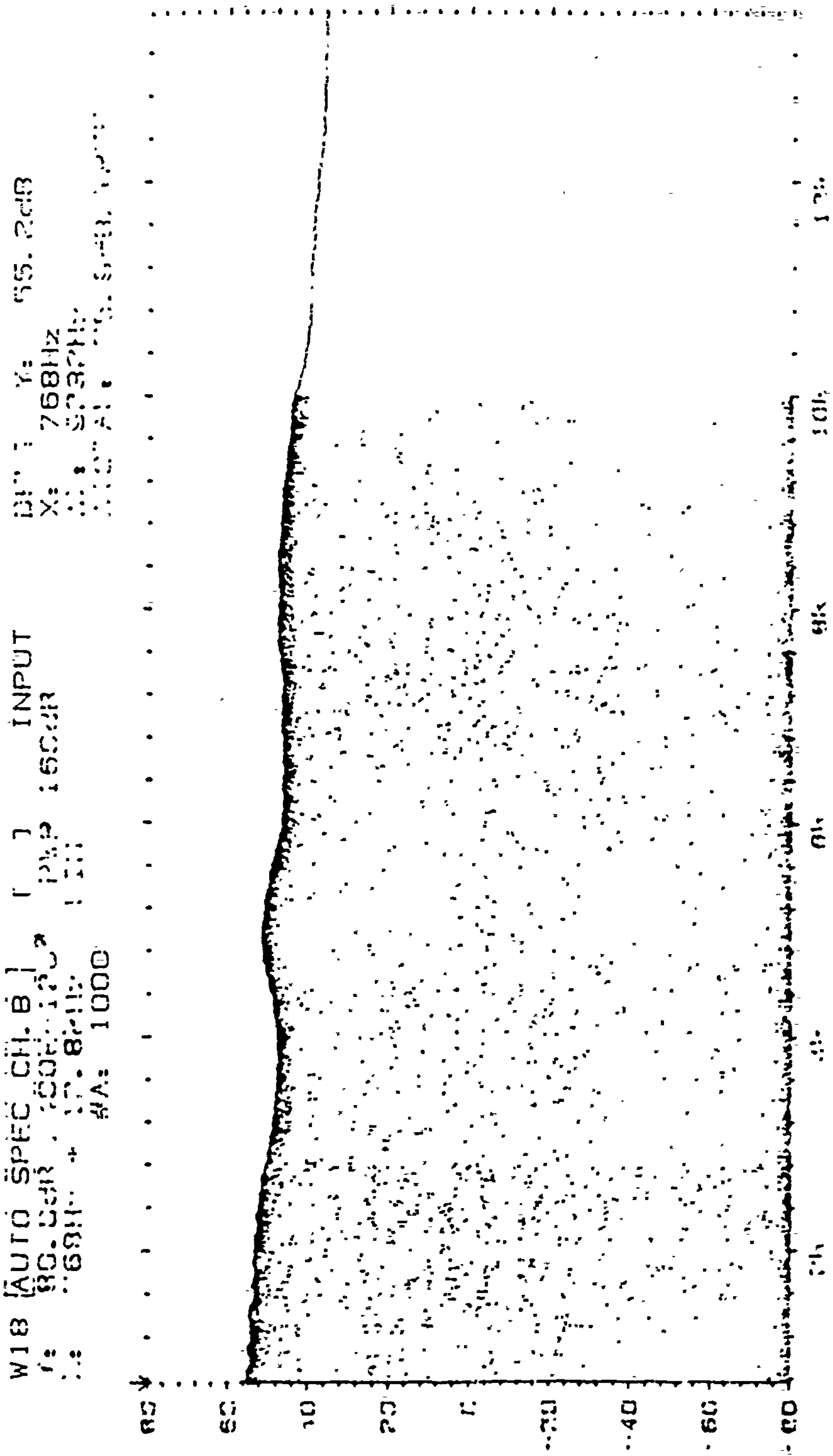


Figure 10: Sample Pressure Level Spectrum, Channel B.

Top Measurements	With BLM					Without BLM				
Air Speed	15.0	20.2	25.7	31.2	36.4	15.0	20.2	25.7	31.2	36.4
Intensity	57.8	67.8	74.7	80.0	84.3	49.5	58.0	64.2	69.4	73.6
Auto Spec.Ch.A	59.6	69.1	75.9	81.2	85.6	54.6	61.5	67.9	73.1	77.4
Auto Spec.Ch.B	60.3	69.1	75.9	81.1	85.5	54.8	61.9	67.8	73.0	77.2
Reactivity Index	-2.15	-1.3	-1.2	-1.15	-1.25	-5.2	-3.7	-3.65	-3.65	-3.7
Side Measurements	**With BLM**					**Without BLM**				
Air Speed	15.0	20.2	25.7	31.2	36.4	15.0	20.2	25.7	31.2	36.4
Intensity	59.5	69.5	75.7	80.8	85.1	49.5	57.5	64.5	69.7	73.3
Auto Spec.Ch.A	62.3	72.0	78.5	83.7	87.9	58.2	62.8	70.1	75.5	79.4
Auto Spec.Ch.B	62.6	71.8	78.3	83.5	87.8	57.1	63.0	70.0	75.3	79.2
Reactivity Index	-2.95	-2.4	-2.7	-2.8	-2.75	-8.15	-5.4	-5.55	-5.7	-6.0

Table 1: Measured Intensity and Pressure Levels and Reactivity Index

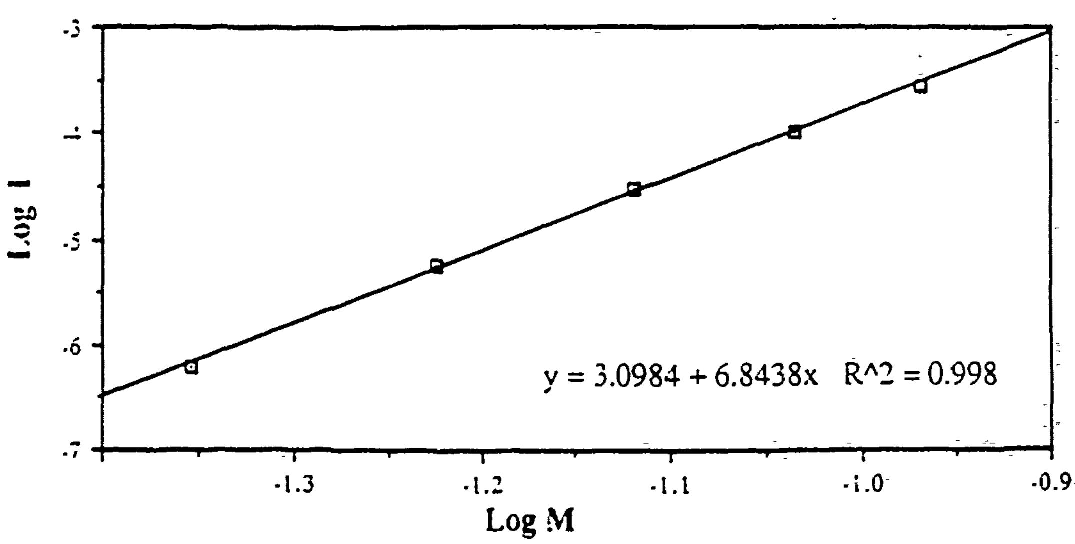


Figure 11: Log I vs. Log M for Measurements Taken Above the BLMs.

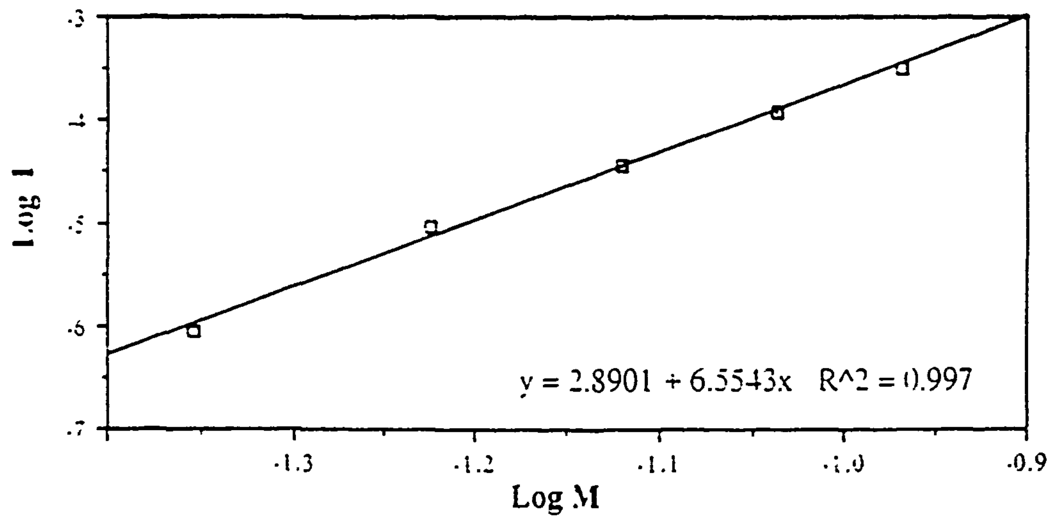


Figure 12: Log I vs. Log M for Measurements Taken Aside the BLMs.

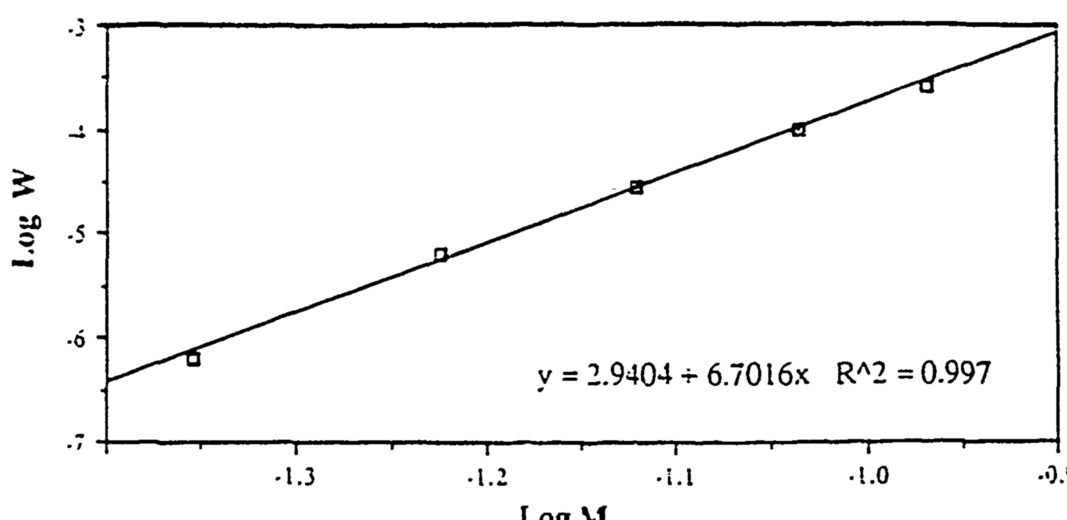


Figure 13: Log W vs. log M for Total Intensity Radiated by BLMs.

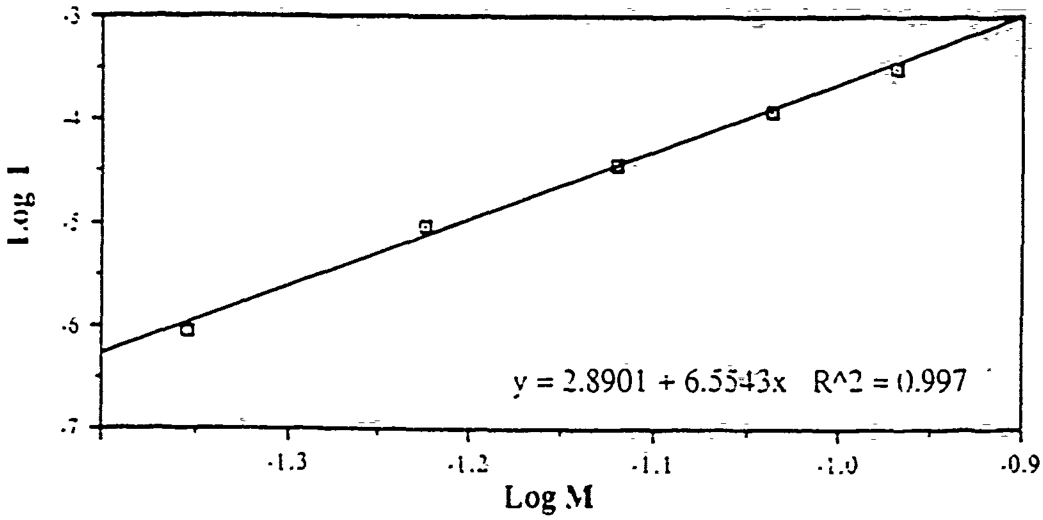


Figure 12: Log I vs. Log M for Measurements Taken Aside the BLMs.

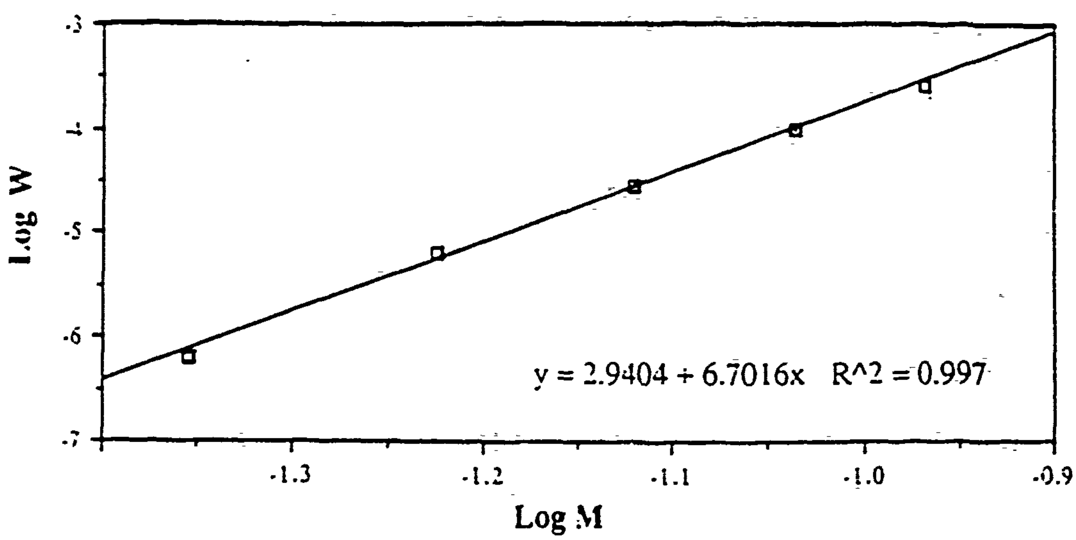


Figure 13: Log W vs. log M for Total Intensity Radiated by BLMs.

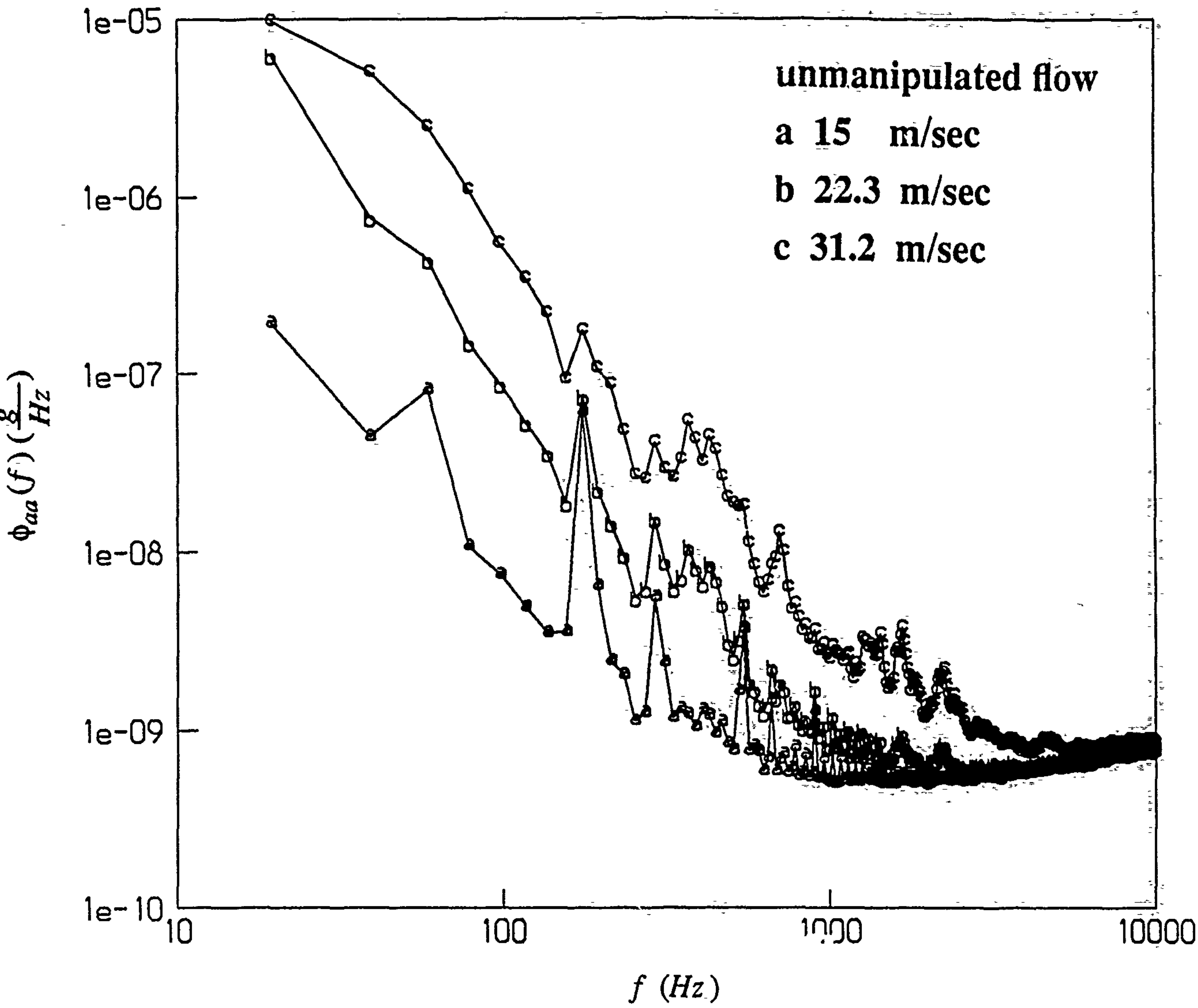


Figure 14: Acceleration Spectra for Unmanipulated Flow

Next we glued BLMs to the forward plexiglass plate as was done in the intensity measurements. Figure (15) shows a comparison between vibration levels of the unmanipulated flow and the manipulated flow, both measurements made directly underneath the first BLM. Figure (16) shows a comparison 11" downstream and Figure (17) shows a comparison 17" downstream of the BLM. As can be seen the vibration levels are significantly higher for the manipulated case close to the BLMs.

The BLMs were constructed of thin sheet metal and are therefore very susceptible to vibrations excited by the turbulent boundary layer. In order to test if it is possible to keep vibration levels down, we glued a thin strip of damping material between the plexiglass and the honeycomb material. Figures (18), (19) and (20) show comparisons of undamped and damped BLM's, underneath 11" and 17" downstream of the device, respectively. Vibration levels have been reduced significantly by using the damping material. For a relative comparison, the power spectra have been integrated between 100 Hz and 10 kHz to give an estimate of the mean square level. Results for an air speed of 22.3 m/sec are listed in Table (2) below.

Even though vibration levels are somewhat raised with BLMs, it should be noted that all levels are very low. In an attempt to measuring sound radiation levels due to plate vibration, we measured sound intensity on a surface opposite to the flow side. However autospectral levels were 18 dB less than on the top side and the reactivity index was too low over most of the control surface to give us confident results. By listening to the sound, we concluded that the measurement is contaminated by either diffraction around the plate edges or reflection from the anechoic treatment at the tunnel walls.

9 Radiation With Damping

Since we used damping material in order to reduce vibration levels, we were curious to know whether sound radiation levels were changed. Intensity levels were measured at the top and side control surface for three different speeds. Figures (21) through (26) show intensity and auto spectra for the top and side measurements. Autospectral values are close to intensity levels to give a small reactivity index. By integrating the spectra between 768 Hz and 10

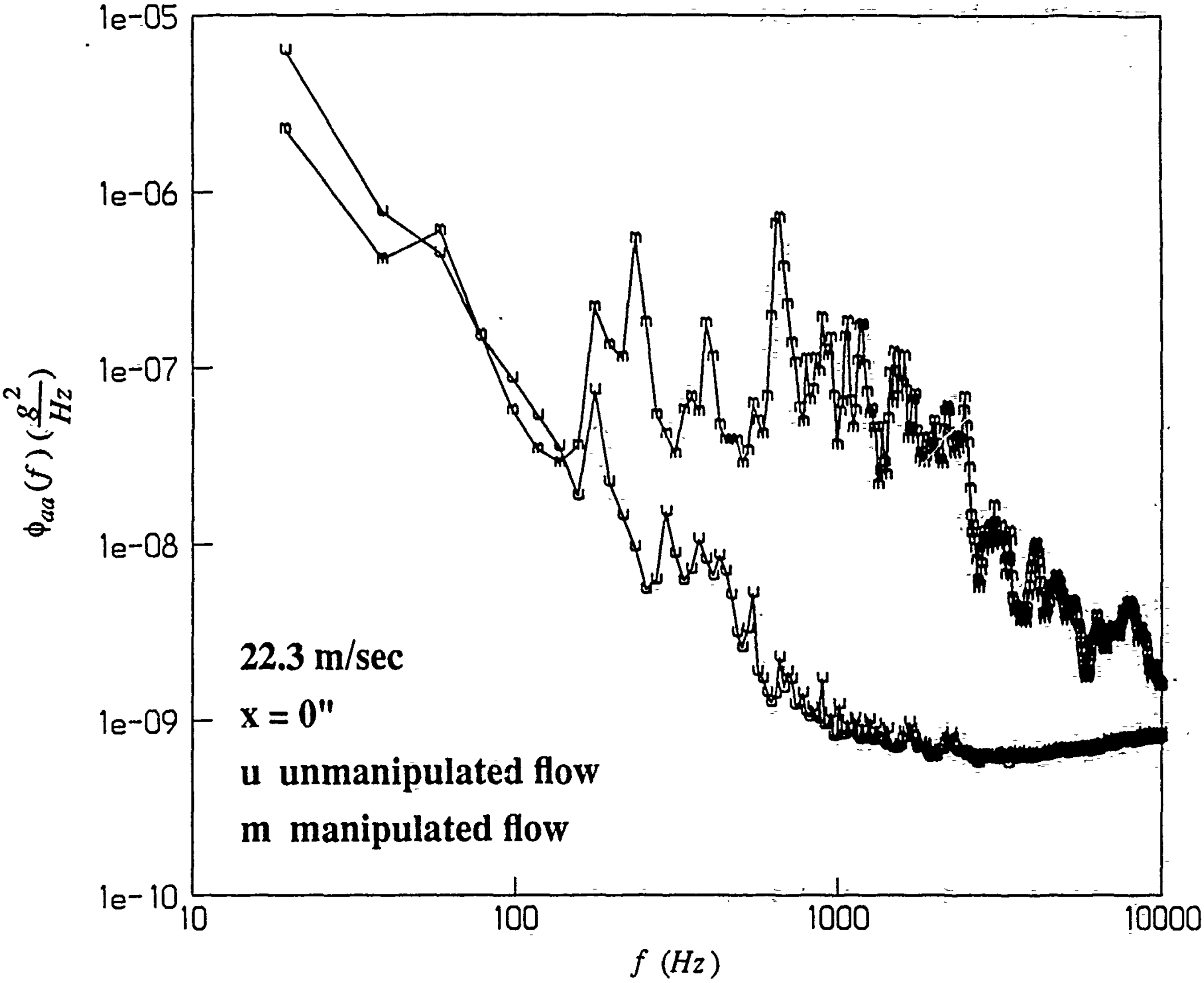


Figure 15: Acceleration Spectra: 22.3 m/sec, $x = 0''$

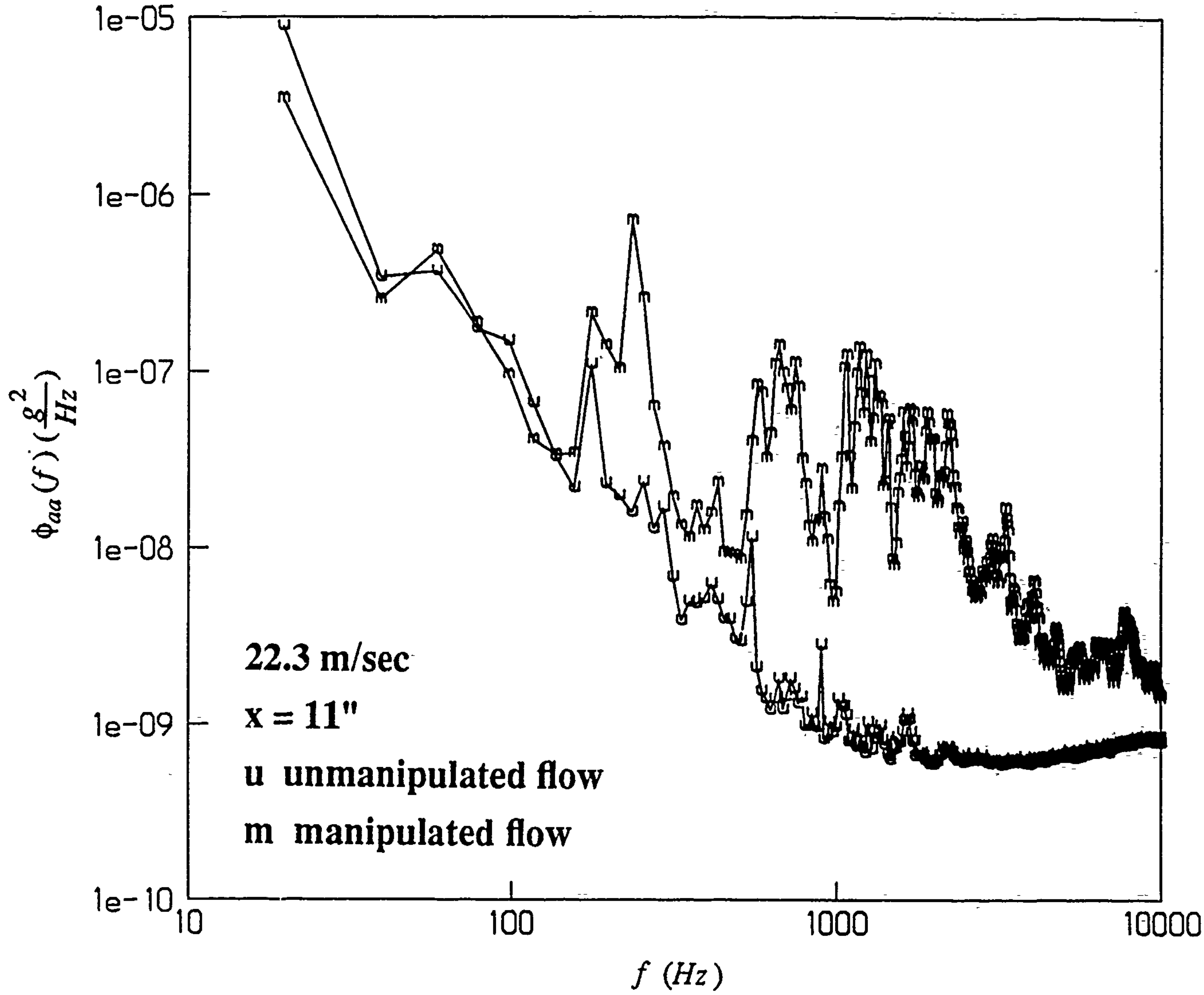


Figure 16: Acceleration Spectra: 22.3 m/sec, $x = 11''$

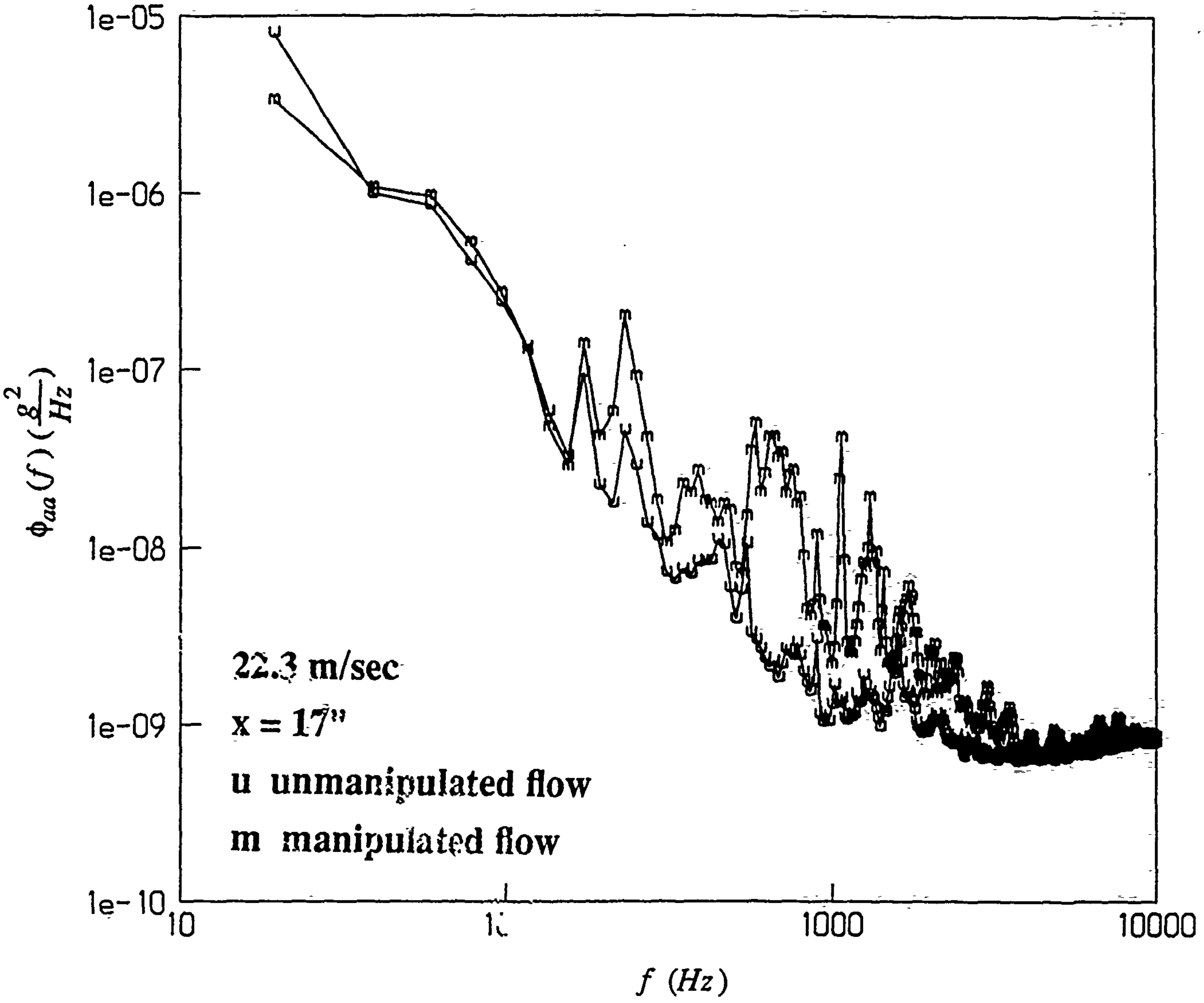


Figure 17: Acceleration Spectra: 22.3 m/sec, $x = 17''$

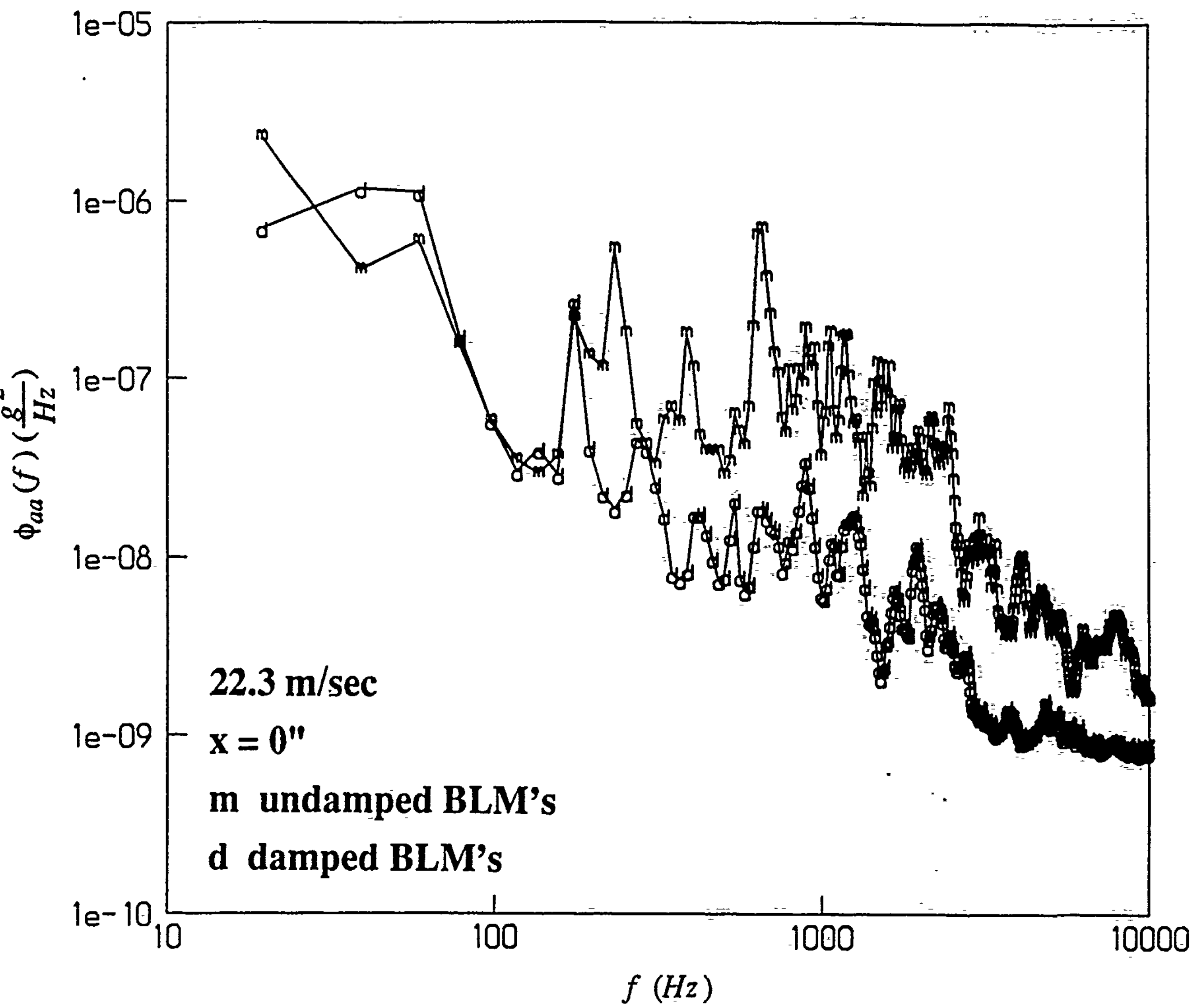


Figure 18: Acceleration Spectra: 22.3 m/sec, $x = 0''$

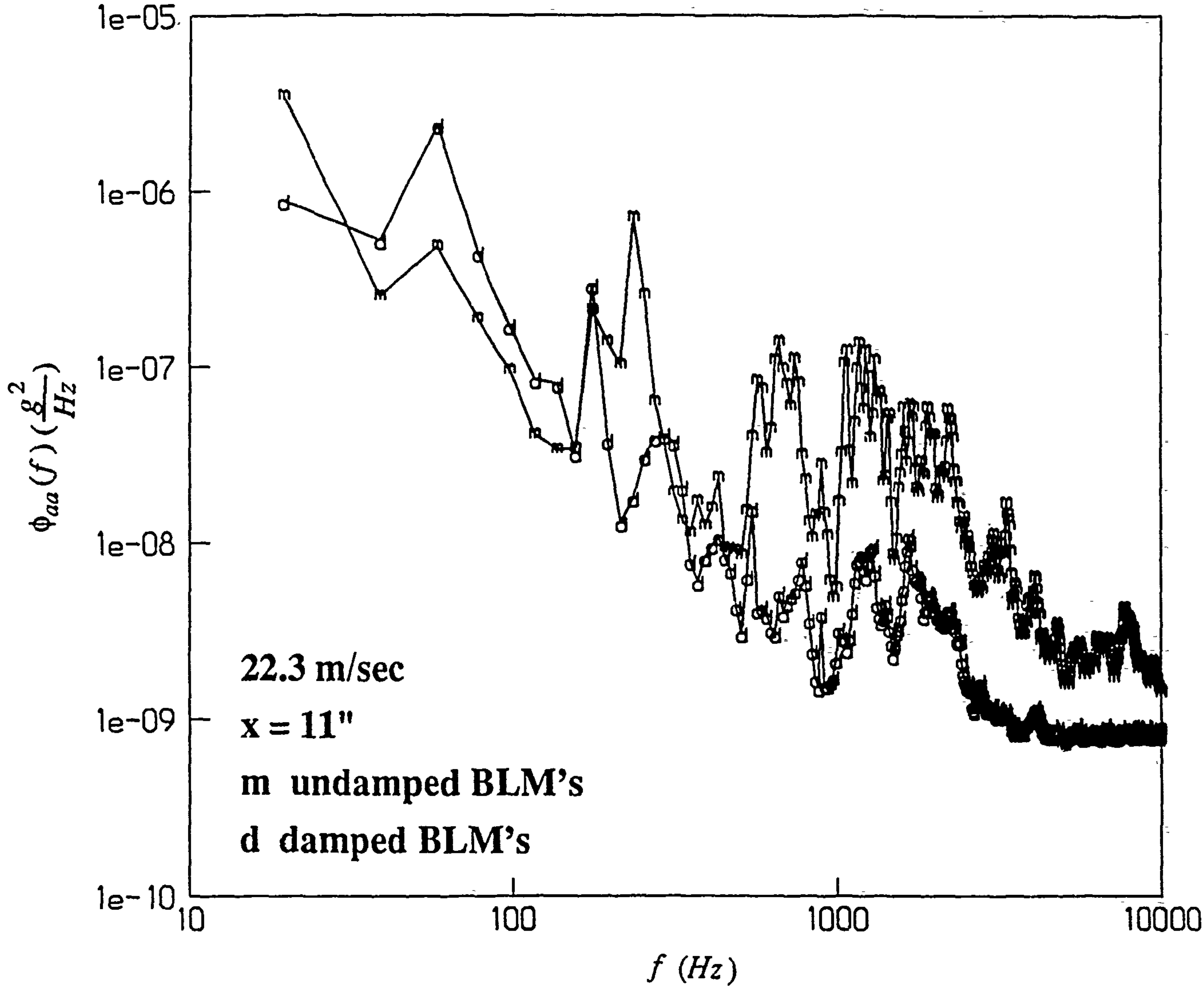


Figure 19: Acceleration Spectra: 22.3 m/sec, $x = 11''$

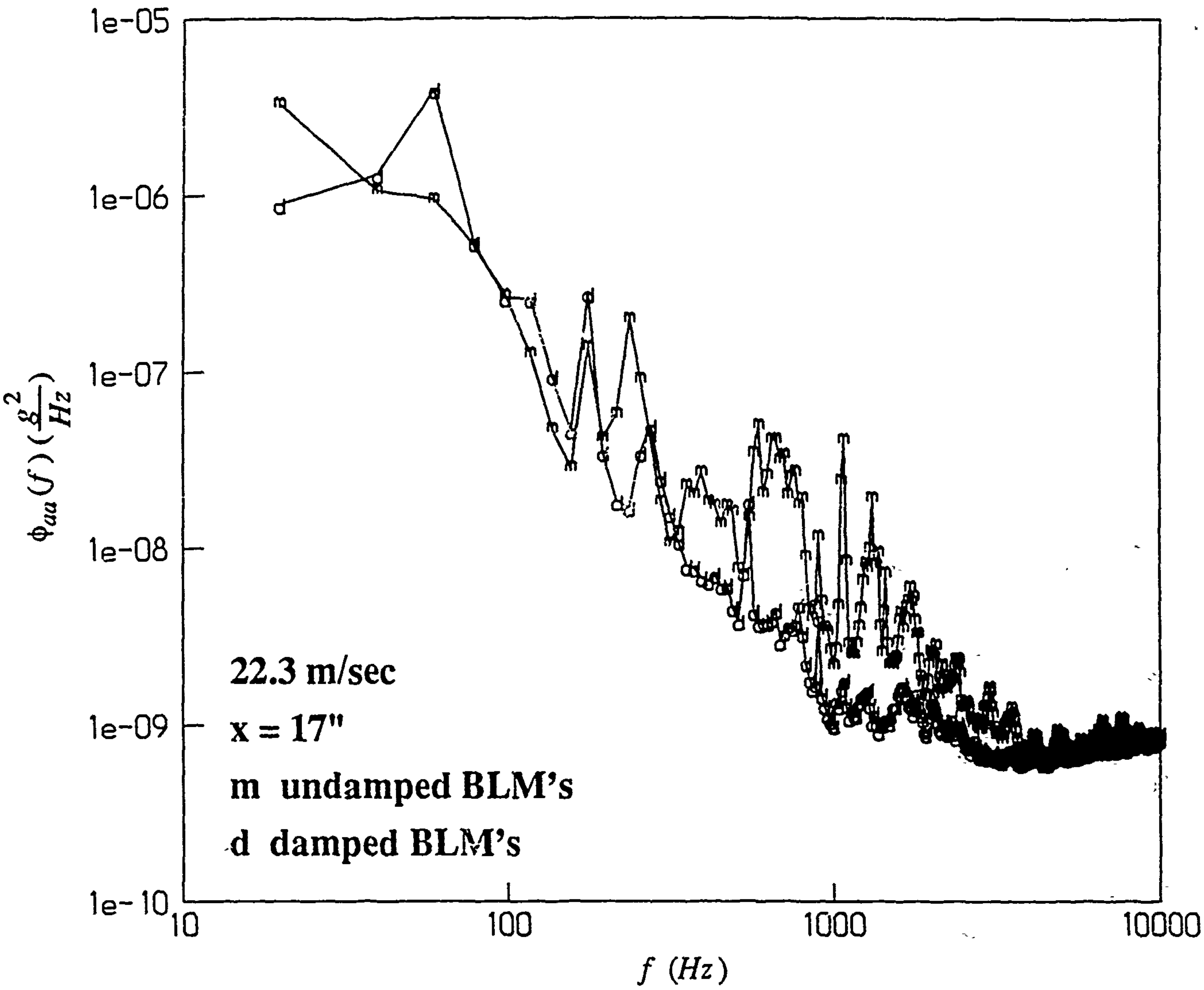


Figure 20: Acceleration Spectra: 22.3 m/sec, $x = 17''$

kHz the intensity levels shown in Table (3) were found. When compared with levels of the undamped BLMs, Intensity levels are between 3 and 6 dB lower for the damped BLMs.

10 Discussion

For a dipole type radiation the stream velocity dependence should be Mach number to the sixth power. Our measurements show a Mach number dependence higher than sixth power. However the measurements were integrated over a fixed band. As velocity increases the nondimensional frequency band decreases which possibly leads to an over estimatation of the Mach number dependence.

Assuming dipole radiation similar to radiation from a cylinder, we can estimate radiation levels in water. The spectral radiated power $\Phi(\omega)$ is proportional to

$$\frac{1}{\rho_0 C_0^3}\overline{f^2}\ell\ell_C\omega^2\Phi_\tau(\omega)$$

(Phillips, 1956) where ρ_0 is the density, C_0 the speed of sound, ℓ the length of the cylinder, $\overline{f^2}$ the mean square force per span, ℓ_C the spanwise correlation length, ω the frequency and Φ_τ is the Fourier transform of the normalized autocorrelation function. If we now set

$$\omega^* = \frac{\omega d}{u_\infty}, C_\ell = \frac{\sqrt{\overline{f^2}}}{\frac{1}{2}\rho_0 U_\infty^2 d}$$

where d is the typical length scale, $U_\infty$the free stream speed and C_ℓ is the unsteady lift coefficient, we get $\phi(\omega^*) \propto \rho_0 C_0^3 C_\ell^2 m^6 \ell\ell_C {\omega^*}^2 \Phi_\tau(\omega^*)$ where ω^* is the Mach number. Then the scaling at the same reduced frequency ω^* with w = water and a = air is :

$$\frac{\Phi_w}{\Phi_a} = \frac{\rho_w}{\rho_a}\left(\frac{C_w}{C_a}\right)^3\left(\frac{M_w}{M_a}\right)^6\left(\frac{L_w}{L_a}\right)^2$$

For example, for

$\rho_w = 998$ Kg/m^3, $Cw = 1500$ m/sec, $U_w = 13$ m/sec, $L_w = 5^1 = 1.54$m

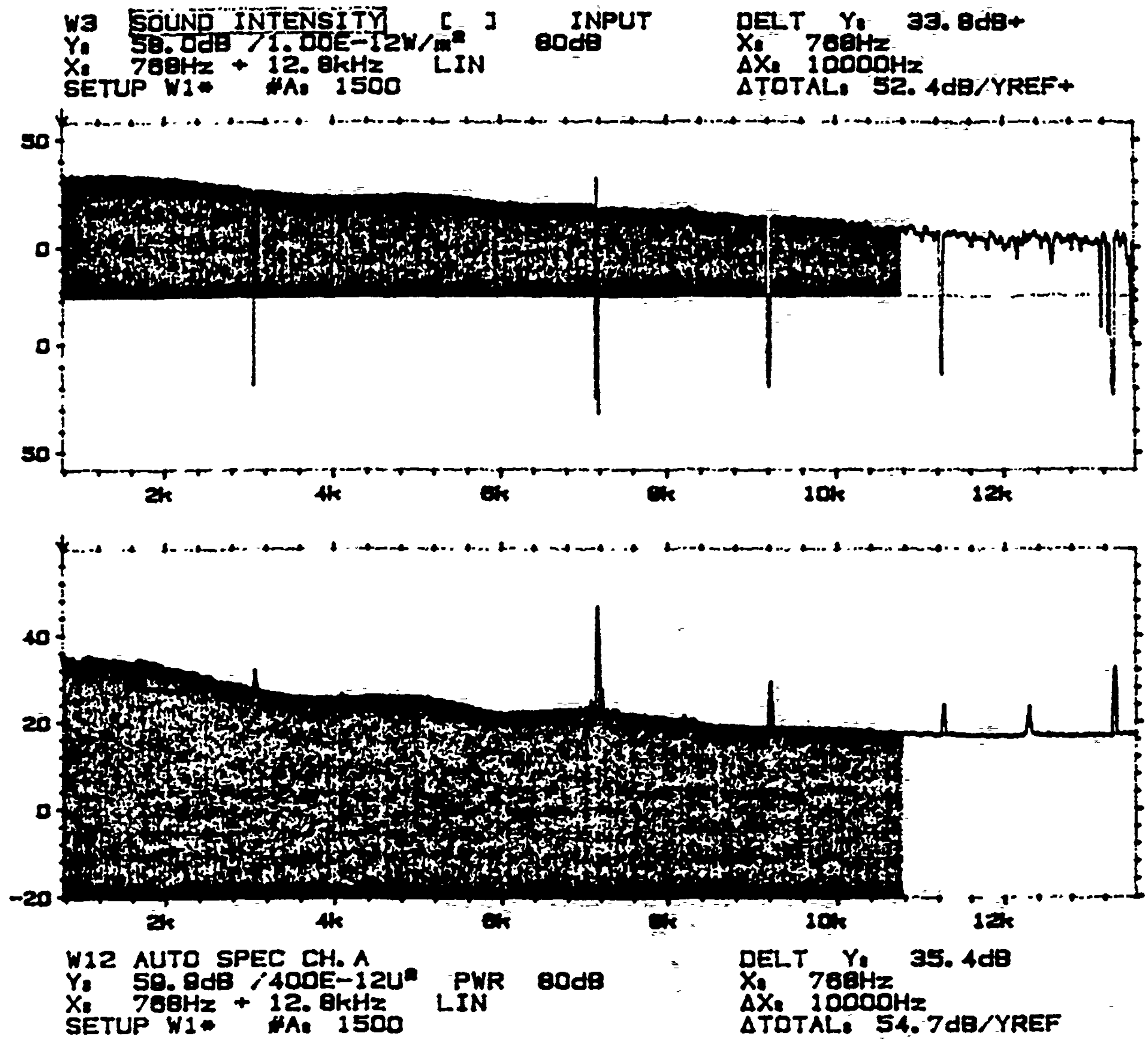
$\rho_a = 1.21$ Kg/m^3, $C_a = 340$ m/sec, $U_a = 25.7$ m/sec, and $L_a = 4$m

	Distance from First BLM (inches)		
	0.0	11.0	17.0
Unmanipulated Flow	9.2	10.6	14.0
Undamped BLMs	213.0	135.0	35.6
Damped BLMs	34.3	26.4	20.8

Table 2: Mean square acceleration levels $\times 10^6\ g^2$

Air Speed (m/sec)	Intensity (dB)	Auto Ch. A (dB)	Auto Ch. B (dB)	Reactivity Index
Top				
15	52.4	54.7	54.5	-2.2
25.7	71.3	72.5	72.6	-1.15
31.2	75.3	76.5	76.4	-1.15
Side				
15	54.3	56.6	56.7	-2.35
25.7	72.4	74.4	74.2	-1.9
31.2	76.4	78.6	78.4	-2.1

Table 3: Intensity levels integrated from 768Hz to 10 kHz



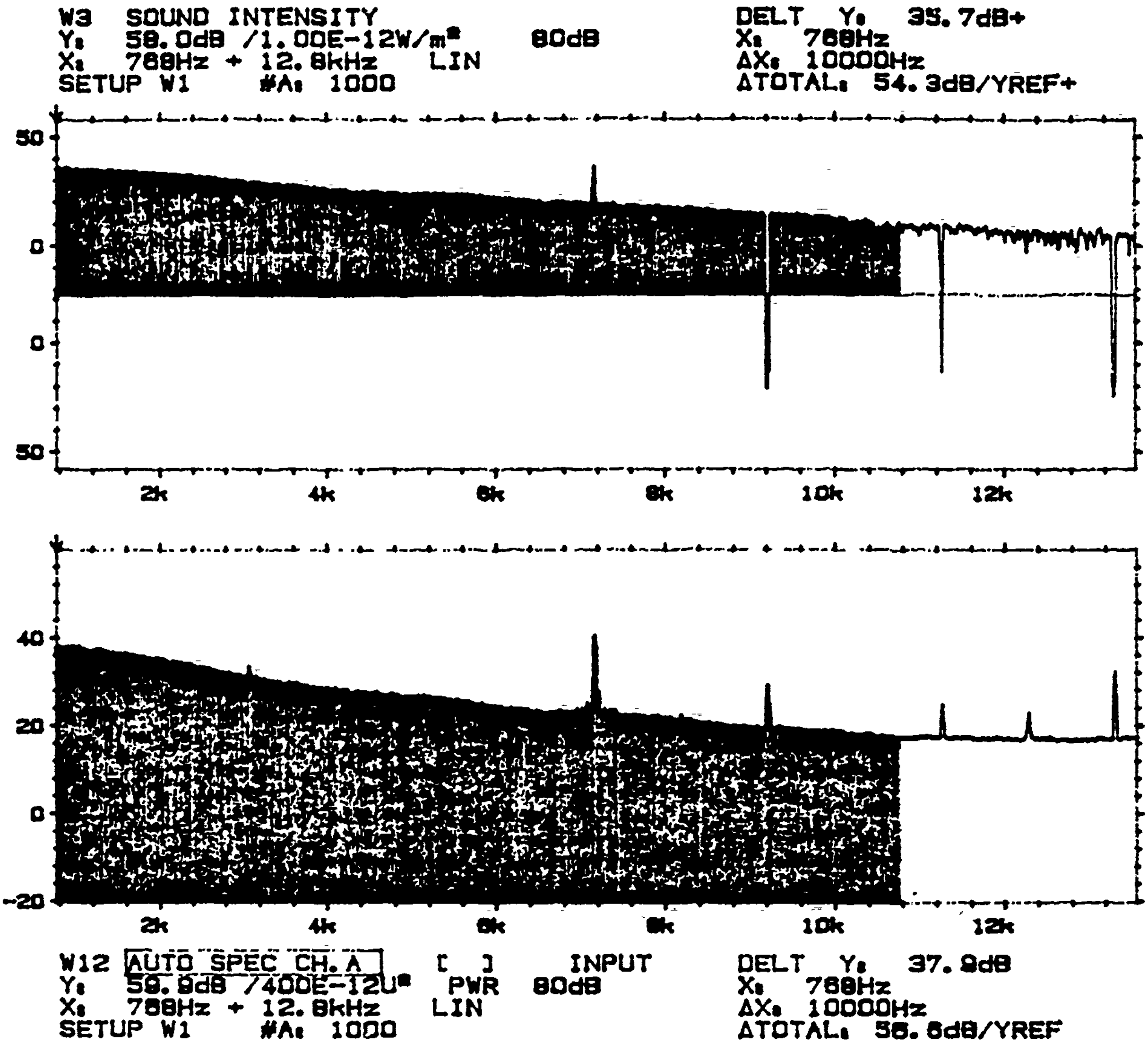
Sound Intensity and Auto Spectrum

15 m/sec

Top Control Surface

Flow with damped BLM's

Figure 21: Sound Intensity and Auto Spectrum, 15m/sec, Top Control Surface



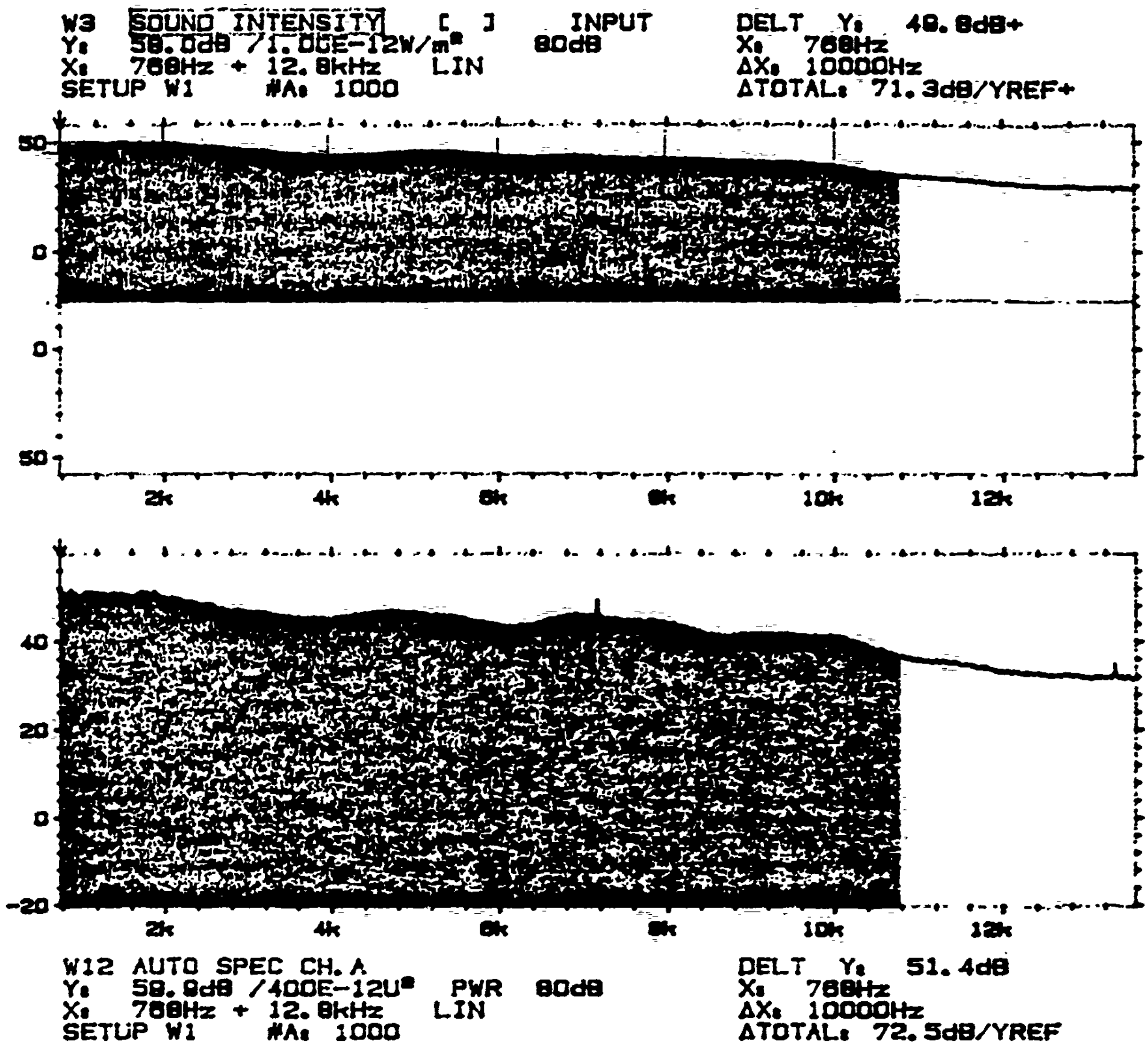
Sound Intensity and Auto Spectrum

15 m/sec

Side Control Surface

Flow with damped BLM's

Figure 22: Sound Intensity and Auto Spectrum, 15 m/sec, Side Control Surface



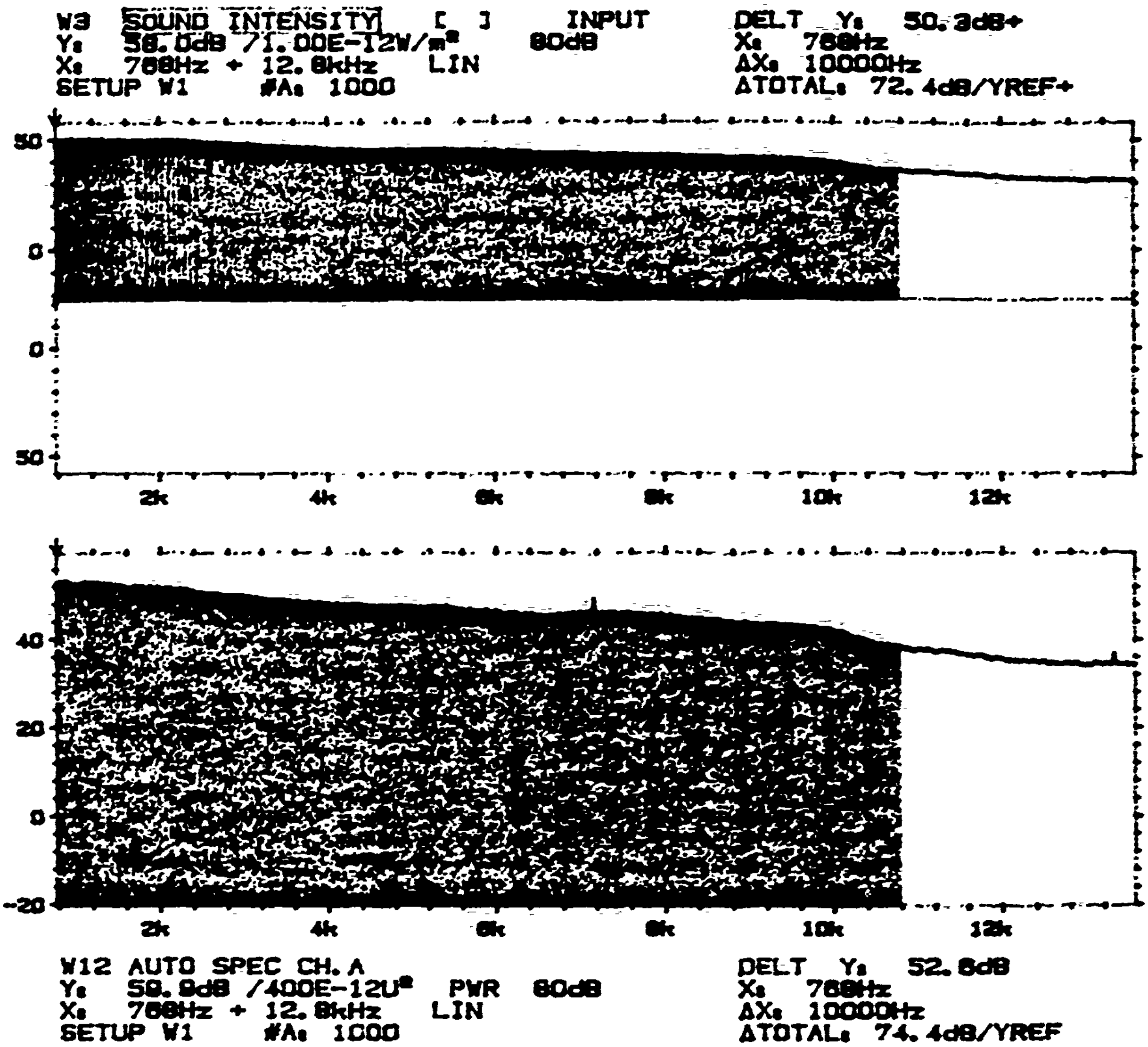
Sound Intensity and Auto Spectrum

25.7 m/sec

Top Control Surface

Flow with damped BLM's

Figure 23: Sound Intensity and Auto Spectrum, 25.7 m/sec, Top Control Surface



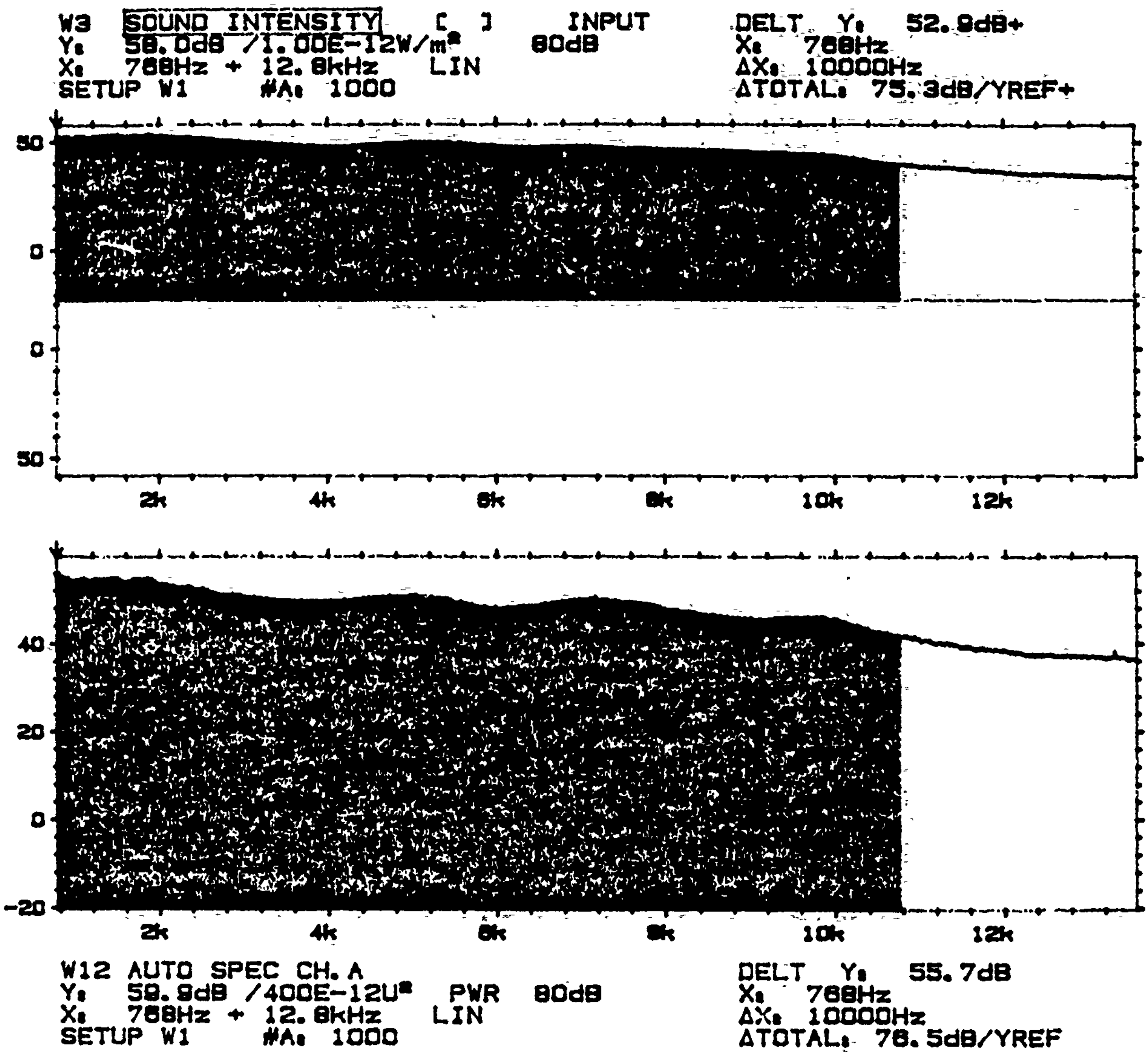
Sound Intensity and Auto Spectrum

25.7 m/sec

Side Control Surface

Flow with damped BLM's

Figure 24: Sound Intensity and Auto Spectrum, 25.7 m/sec, Side Control Surface



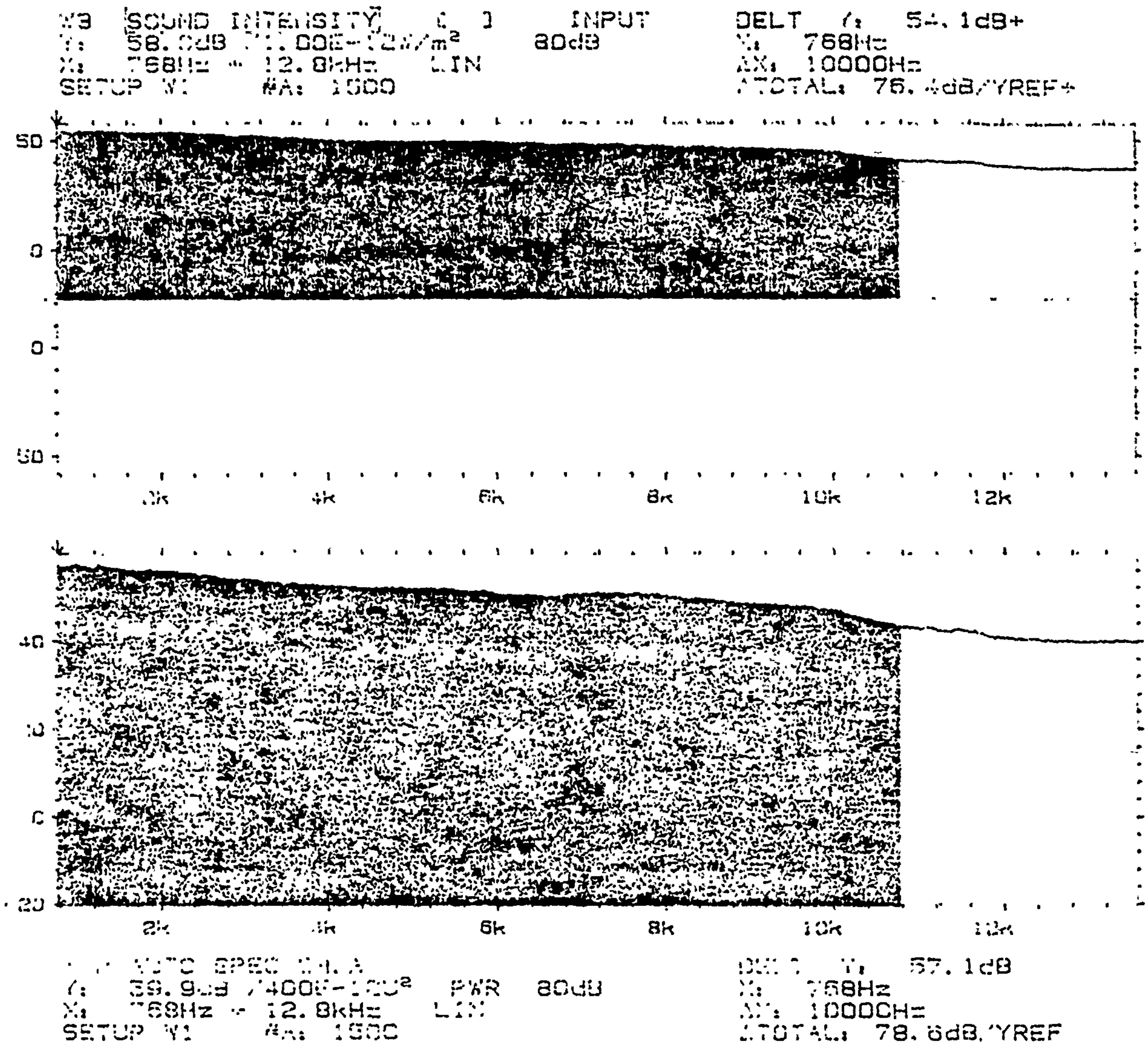
Sound Intensity and Auto Spectrum

31.2 m/sec

Top Control Surface

Flow with damped BLM's

Figure 25: Sound Intensity and Auto Spectrum, 31.2 m/sec, Top Control Surface



Sound Intensity and Auto Spectrum

31.2 m/sec

Side Control Surface

Flow with damped BLM's

Figure 26: Sound Intensity and Auto Spectrum, 31.2 m/sec, Side Control Surface

we get

$$\frac{\Phi_w}{\Phi_a} = 2.385.$$

Using experimental values from our air measurements for these values, we find that pressure spectral levels in water at 100m correspond to a sea state of less than $\frac{1}{2}$ over the measured frequency range.

A dramatic reduction of radiation occurs when damping material is used on the BLMs. This suggests that unsteady lift forces are reduced by the damping. Our results therefore indicate that BLMs could be used on naval vessels without significant radiation or vibration levels. However proper damping of the device is an important facter in the design of a BLM.

A Measurement Difficulties

Several problems were encountered while using the intensity probe and analyzer, and so that others may benefit from my experience these problems and their solutions are detailed here.

In order to determine the reactivity index, the total intensity level and pressure level for the frequency range of interest must be determined. The analyzer is normally able to provide these figures. However, a limitation of the analyzer was encountered which rendered the original total intensity and pressure readings unusable.

The pressure level should always be equal to or higher than the intensity level for the following reason. In the free field in air, the pressure level, which is a scalar quantity, should be equal in magnitude to the intensity level, a vector quantity, if the sound is directed parallel to the probe axis, at an angle of incidence $\Theta = 0$. If the sound reaches the intensity probe at an angle $\Theta > 0$, the intensity will be reduced by a factor of $(\cos\Theta)$, while the pressure level will remain the same. Under these conditions it is obvious that the pressure level should always be higher than the intensity level, causing the reactivity index to be negative.

However, if the entire low frequency range was measured, without use of the analyzer's zoom feature, the total intensity level given by the analyzer was always higher than the total pressure level. In instances where the intensity and pressure spectra were virtually identical, which occurred for the

intensity measurements with the BLMs in the tunnel, the intensity level was approximately 5 dB greater than the pressure level (Figures (27) and (28)).

For the background measurements, in which the graphs show that the pressure level was consistently higher than the intensity level across the entire high frequency spectrum, the discrepancy is even greater, with intensity levels averaging about 7 dB higher than pressure levels (Figures (29) and (30)).

The problem was caused by the manner in which the instrumentation deals with low frequency sound intensity levels. An incorrect value for the total intensity is measured in the low frequency bands, with values exceeding the actual intensity level by a large amount. The discrepancy is large enough to completely overcome the expected difference between the pressure and intensity levels across the entire spectrum. By comparing the levels in each band it was determined that the measured intensities below approximately 250 Hz were incorrect. In order to eliminate the contribution of these intensities to the overall total, the low frequency range was ignored entirely, using the zoom feature of the analyzer.

Another problem which affected the intensity measurements was due to the construction of the intensity probe itself. In order to minimize the interference with the sound propagation patterns due to wave reflections off of the probe, the probe is constructed of cylindrical rods, which are pressure fitted together to form the probe frame. The probe became loose at the two joints in the frame for the outer microphone, and this caused several problems. First, the intensity spectra showed negatively directed intensities at low frequencies, below 1 kHz, due to the vibration of the probe frame. Second, the intensity spectra had two peaks, one at approximately 1 kHz and a much smaller one at approximately 2 kHz (Figure (31)). Lastly, the microphone became overloaded frequently because of the vibration of the preamplifier wires which run through the probe frame.

These three problems were eliminated by gluing the frame at each of the two loose joints, and taping the preamplifier wire to the probe frame as a strain relief. The outer microphone is still sensitive to vibrations, possibly due to a problem with the preamplifier wires; however, these problems can be avoided if care is taken to avoid bumping the probe during each measurement. The probe should be checked periodically to ensure that the frame has not loosened. These precautions should help to preserve the overall accuracy of data measurements using this equipment.

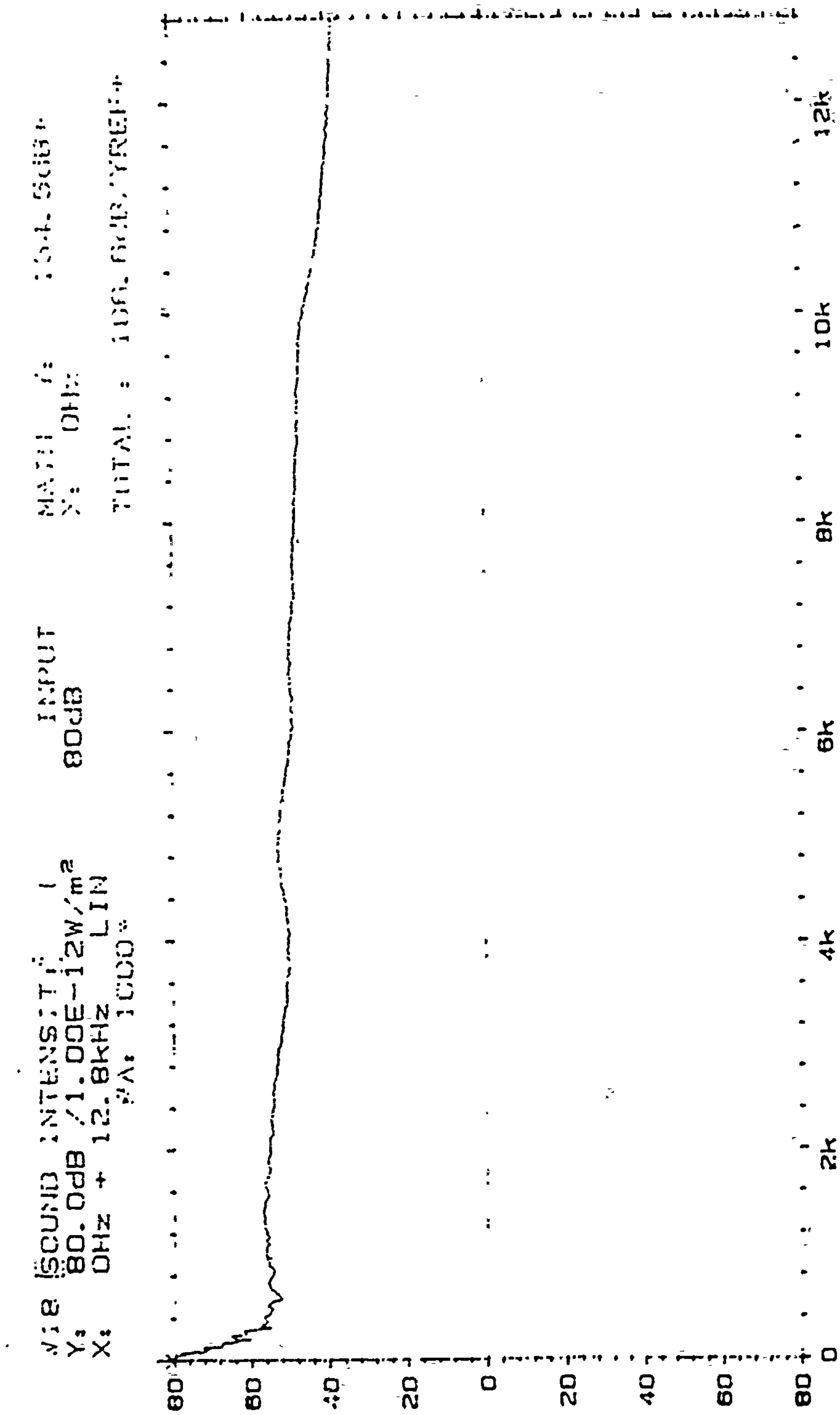


Figure 27: Intensity Level Spectrum Showing Incorrect Total Intensity

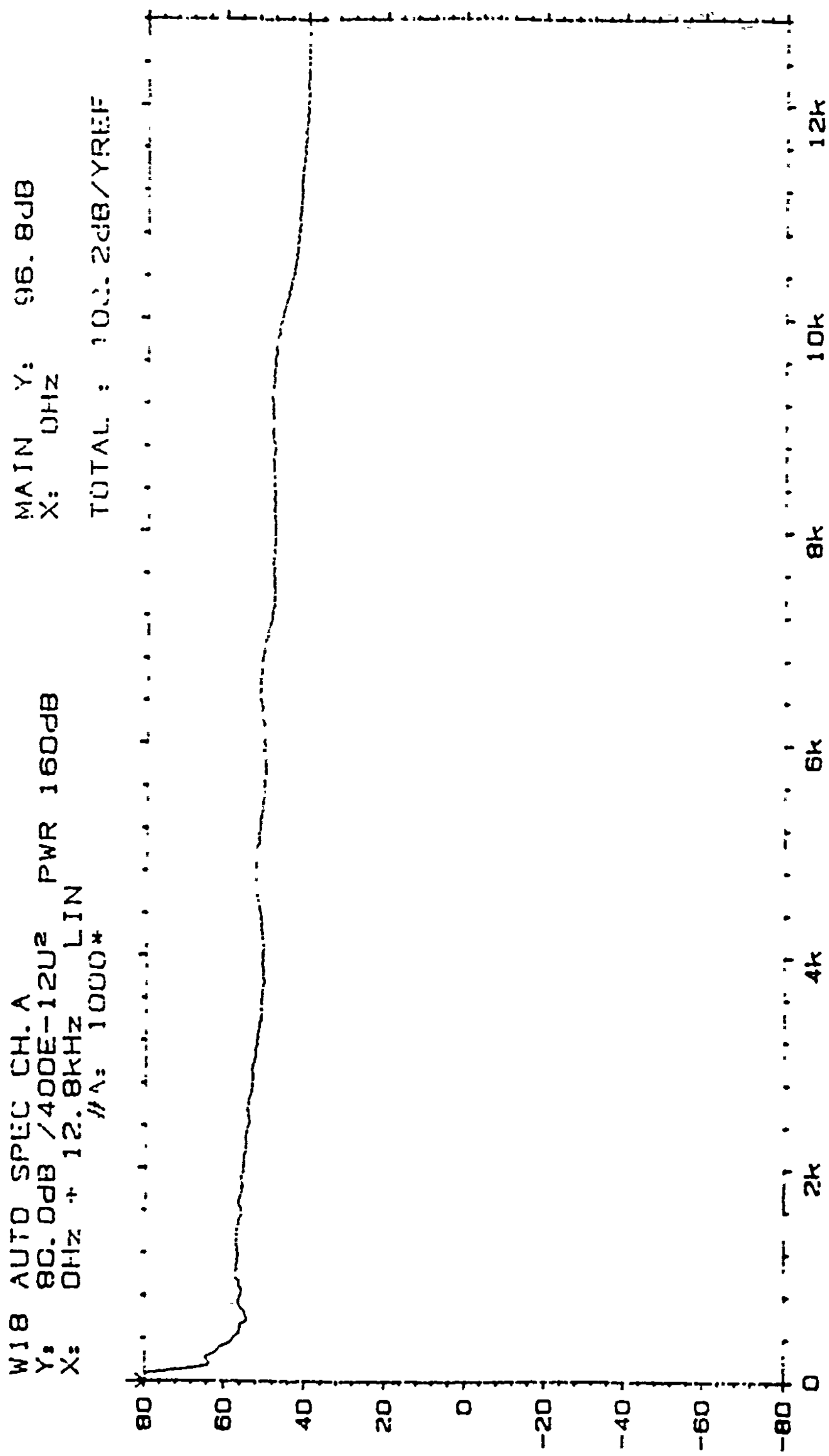


Figure 28: Corresponding Pressure level Spectrum with Incorrect total

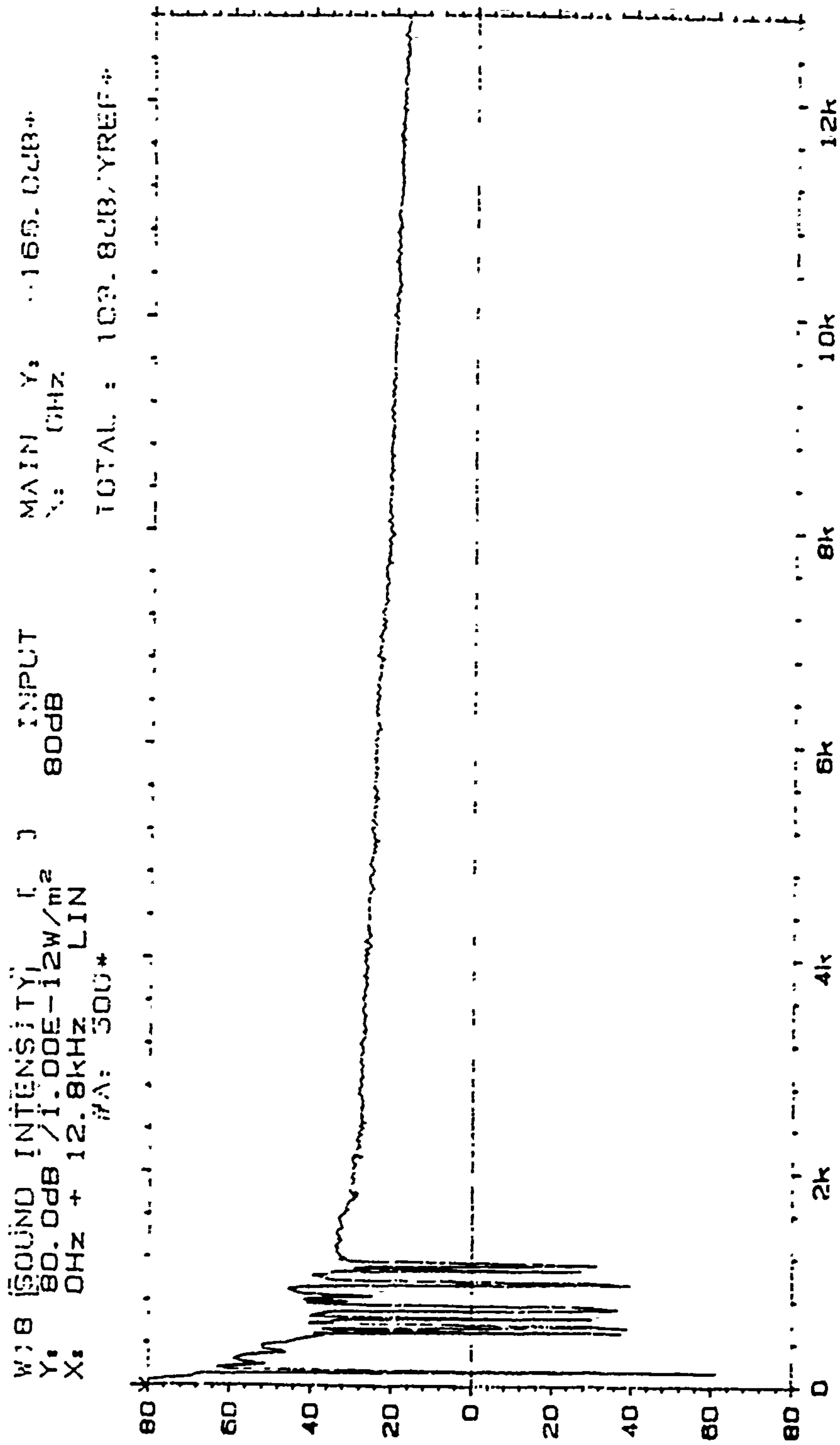


Figure 29: Intensity Level for background Measurement

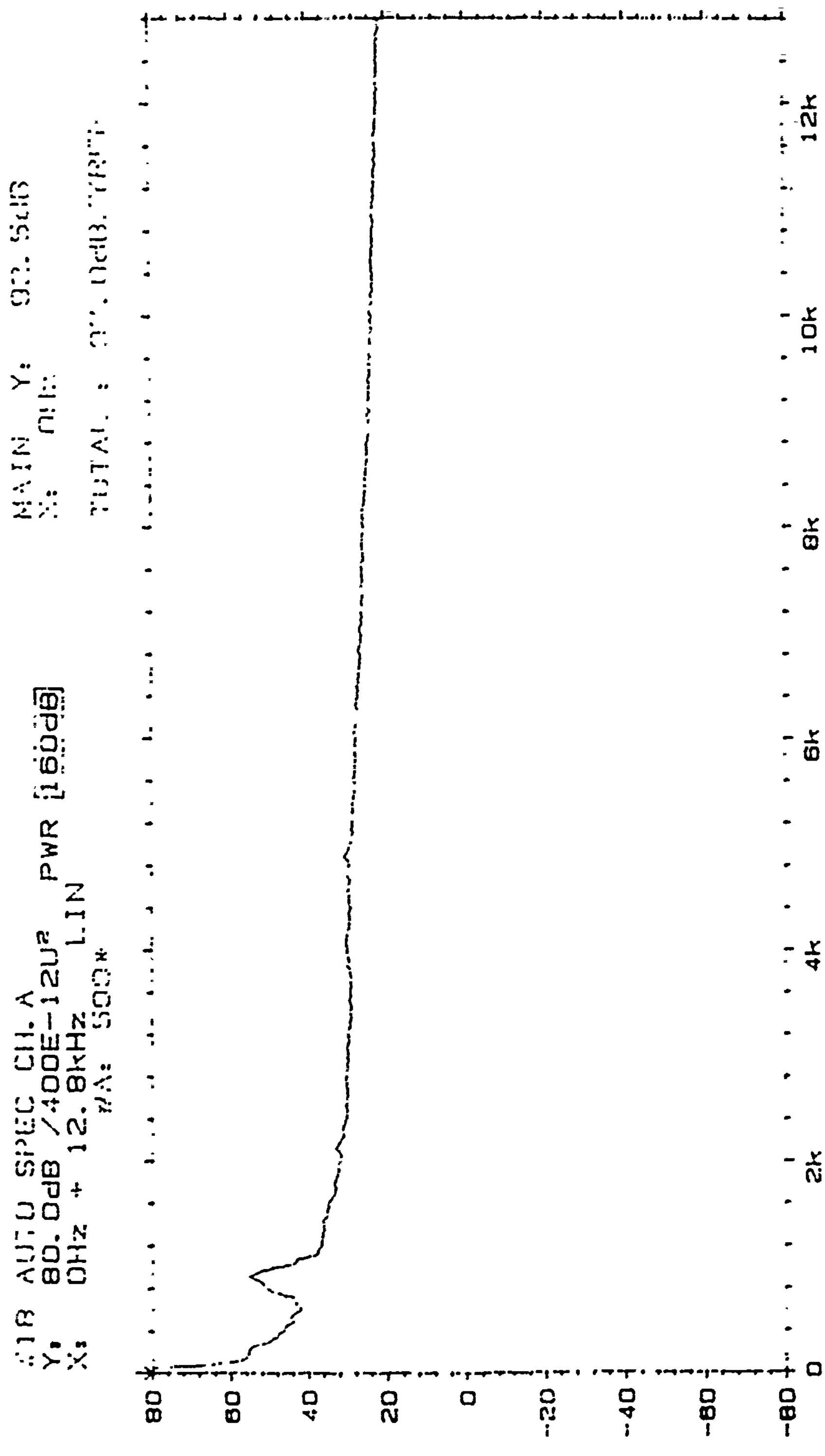


Figure 30: Corresponding Pressure Level for Background Measurement

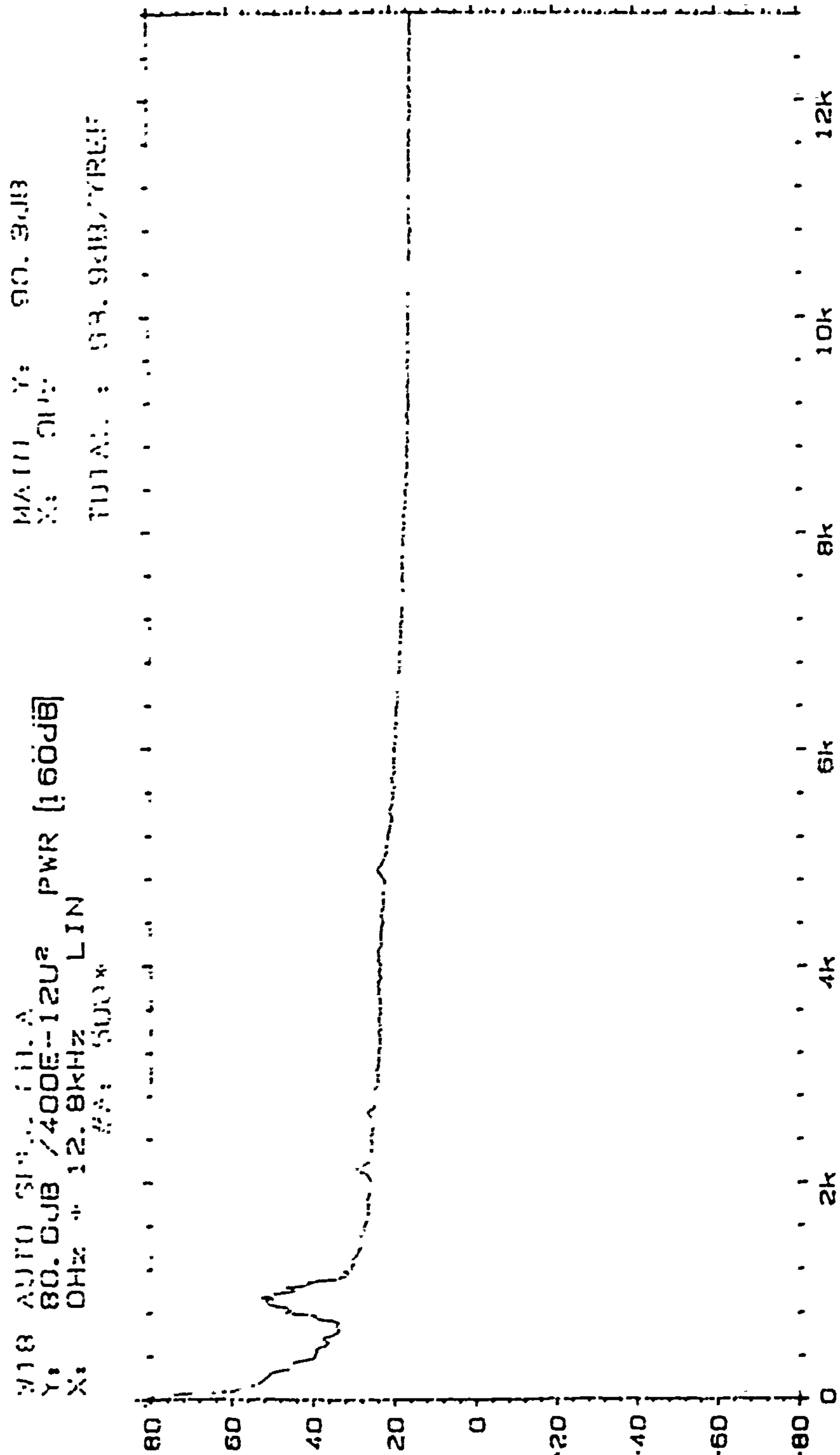


Figure 31: Pressure Spectrum Showing 1 kHz Anomaly

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